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(54) **OPTICAL INFORMATION RECORDING AND REPRODUCING APPARATUS**

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US 2007/0121468 A1   May 31, 2007

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Nov. 29, 2005	(JP)	....	2005-343884
May 10, 2006	(JP)	....	2006-131450
Nov. 14, 2006	(JP)	....	2006-307896

(51) **Int. Cl.**
G11B 7/00   (2006.01)
(52) **U.S. Cl.** **369/103**
(58) **Field of Classification Search** 369/103, 369/44.12, 112.01, 112.02, 112.1; 359/3, 359/22, 238
See application file for complete search history.

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(74) *Attorney, Agent, or Firm*—Fitzpatrick, Cella, Harper & Scinto

(57) **ABSTRACT**

Provided is a spatial light modulator SLM and a photodetector element CMOS sensor are placed on the same chip, and the alignment thereof and a relay lens system are eliminated, whereby an optical system is reduced in cost and made compact. Specifically, provided is an optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light including: a light source; a spatial light modulator for generating at least an information light with respect to a light beam from the light source; an objective lens for irradiating a recording medium with the light beam from the spatial light modulator; and a photodetector element for receiving a reproduction light from the recording medium, in which the spatial light modulator and the photodetector element are formed on the same semiconductor substrate.

11 Claims, 36 Drawing Sheets
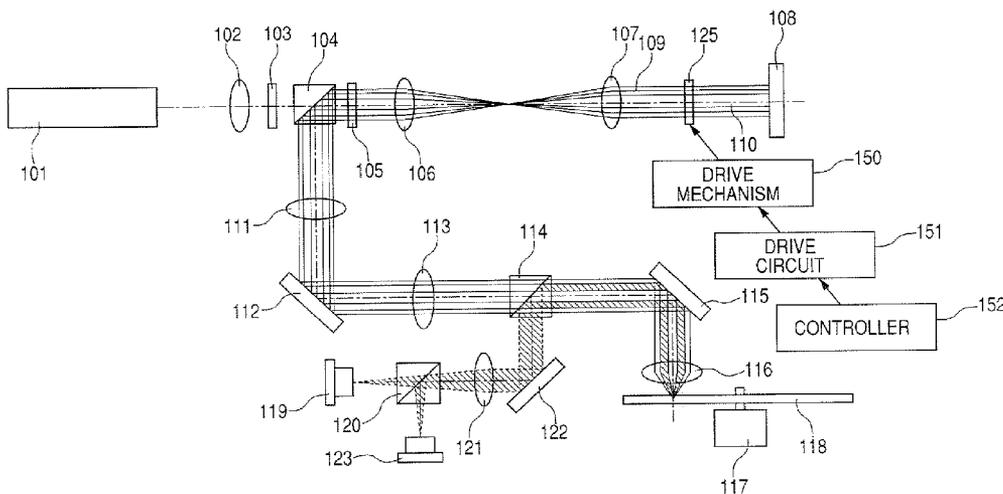
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FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

RECORDING MODE

(1): WIDE GAP (170nm)

(2): NARROW GAP (10nm)

FIG. 7

READOUT MODE
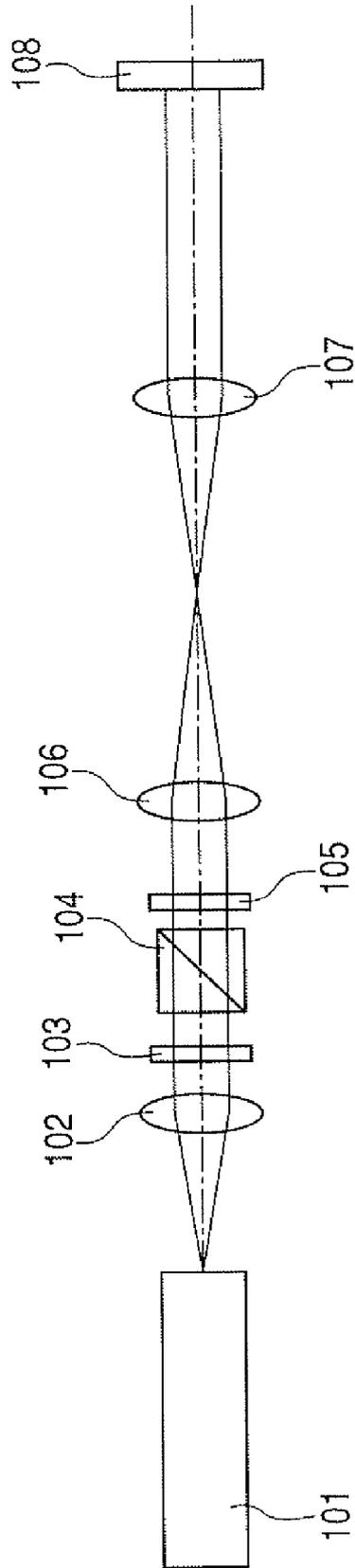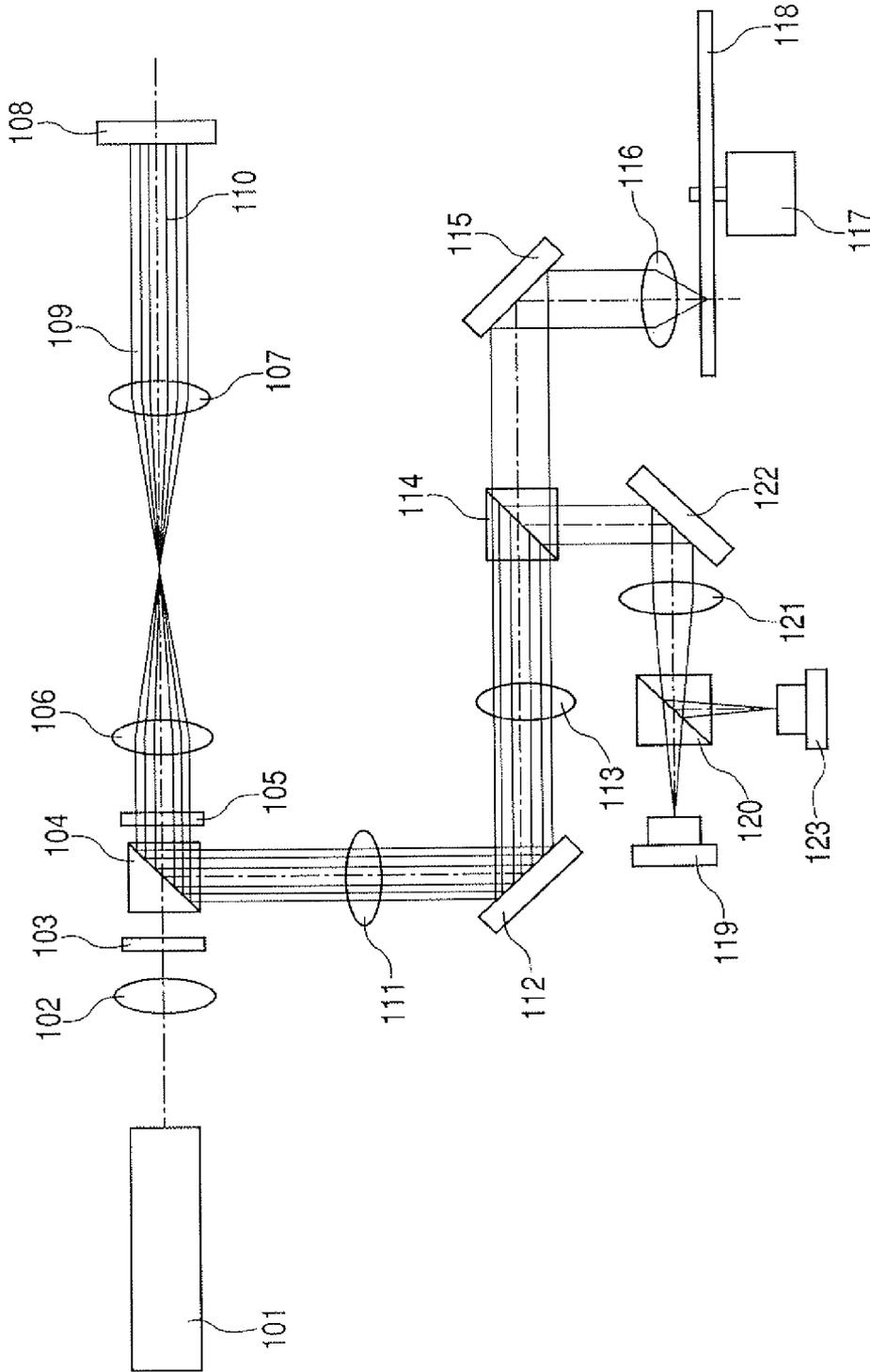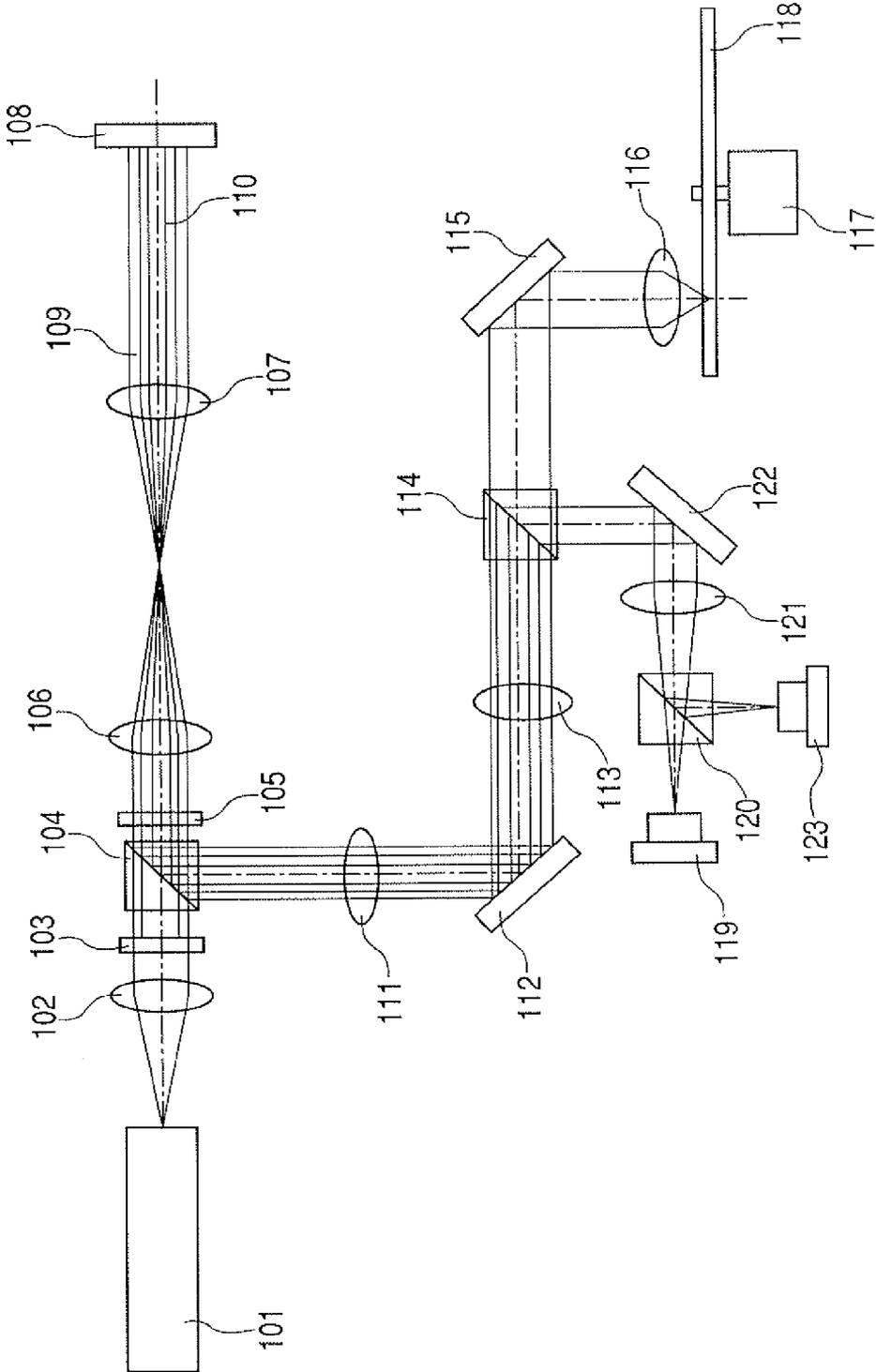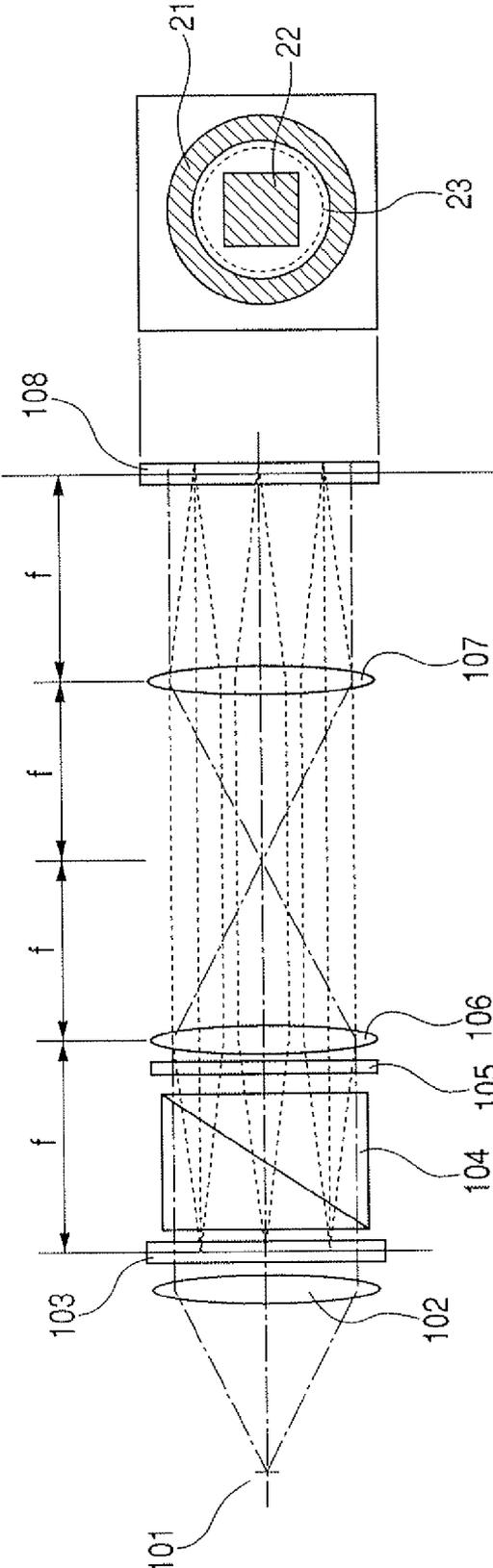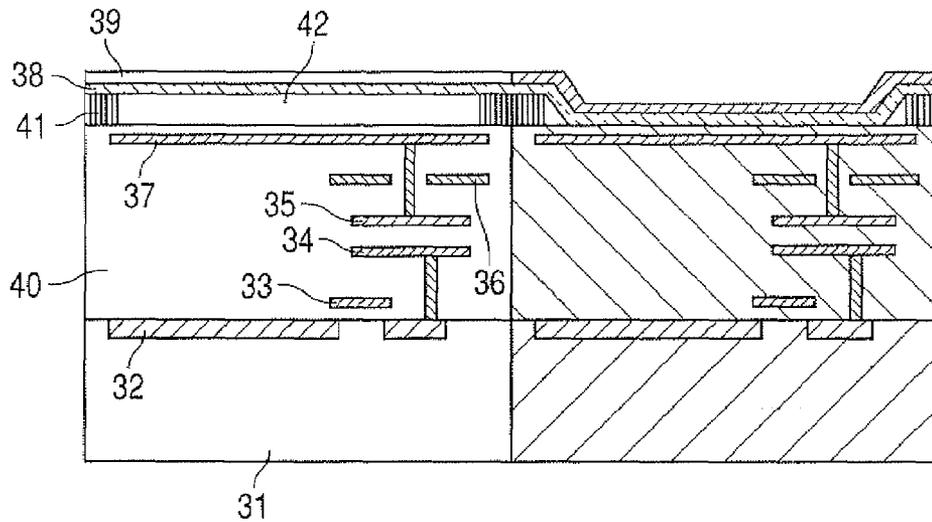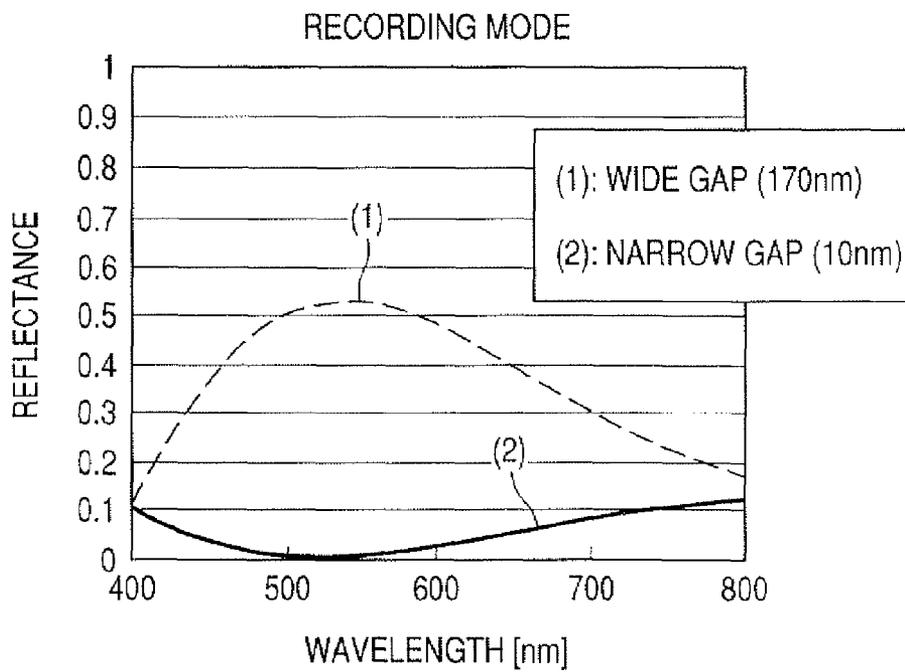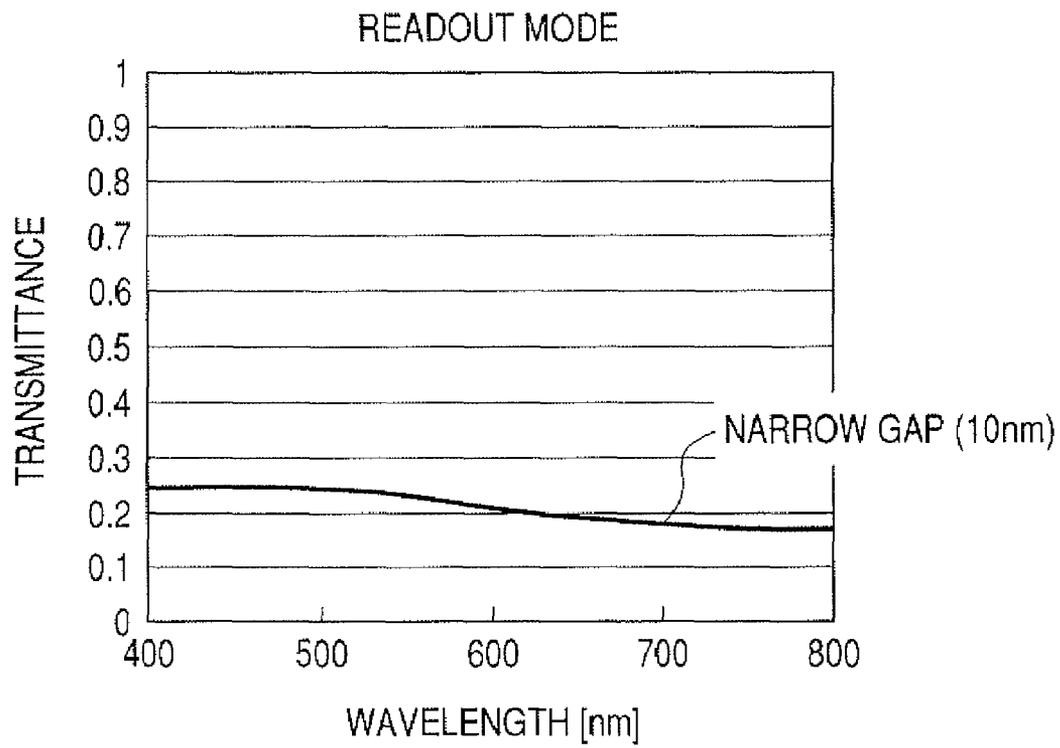
FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG. 12

FIG. 13

FIG. 14

FIG. 15

PARALLEL PLATE TILT vs PARALLEL SHIFT

FIG. 16

FIG. 17

RECORDING MODE

(1): WIDE GAP (180nm)

(2): NARROW GAP (10nm)

FIG. 18

FIG. 19
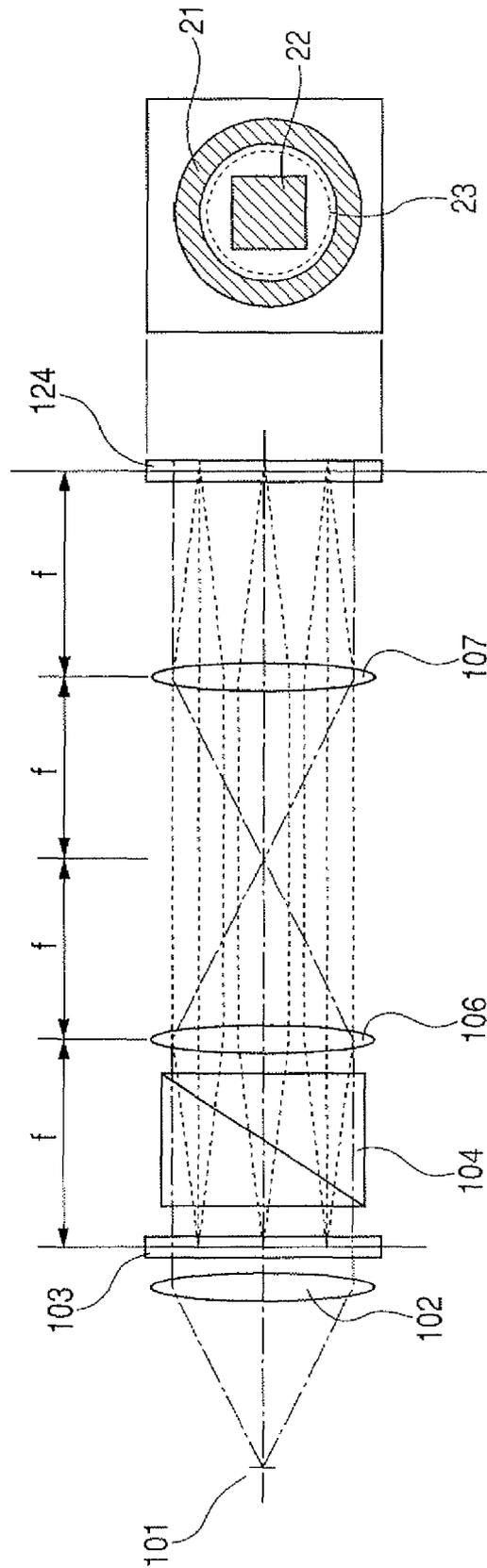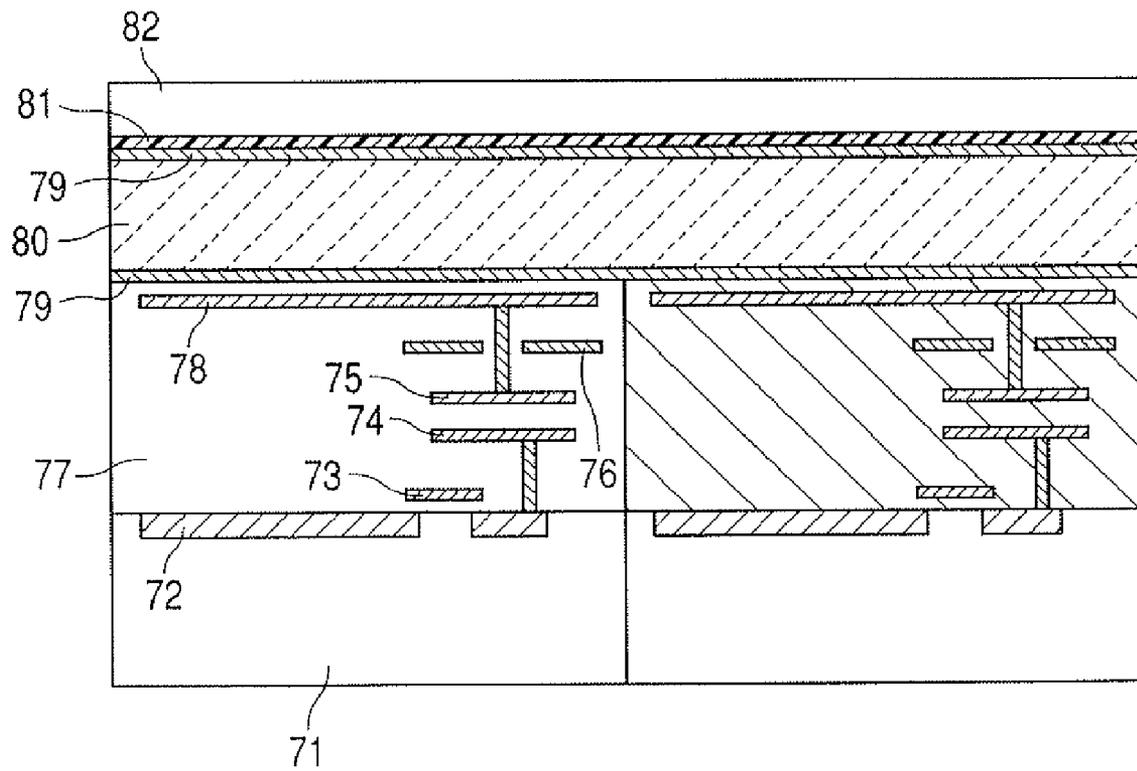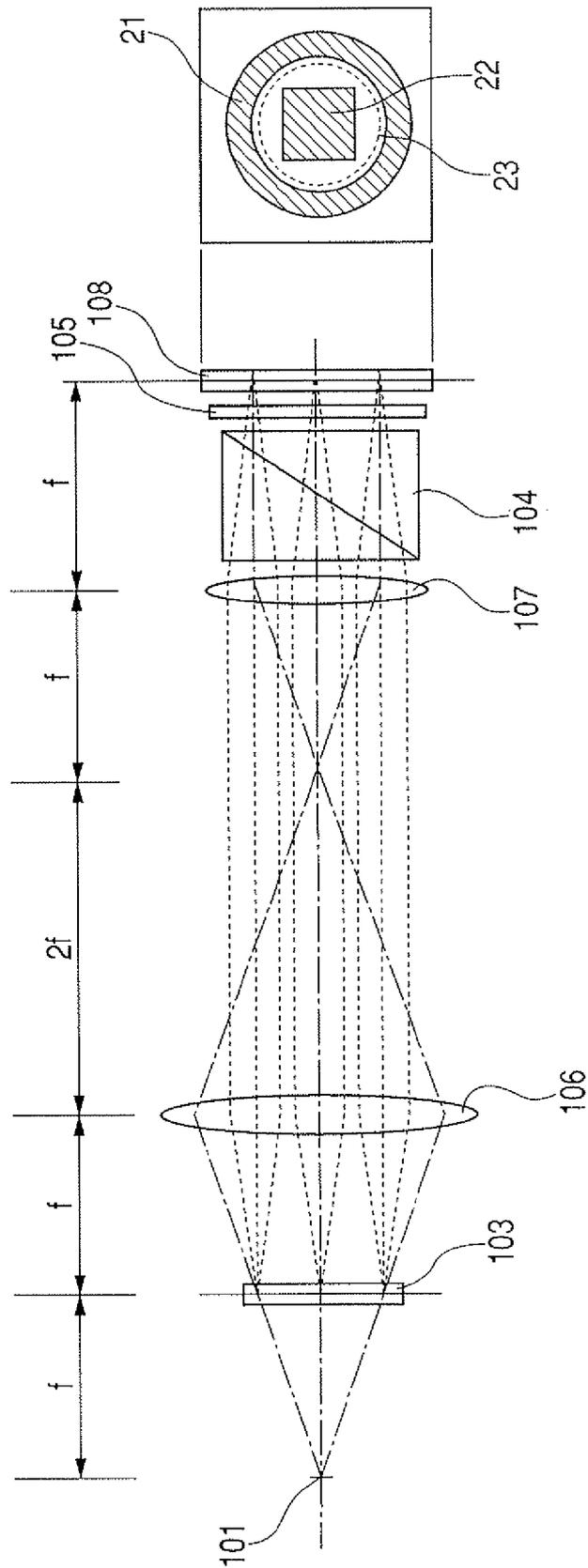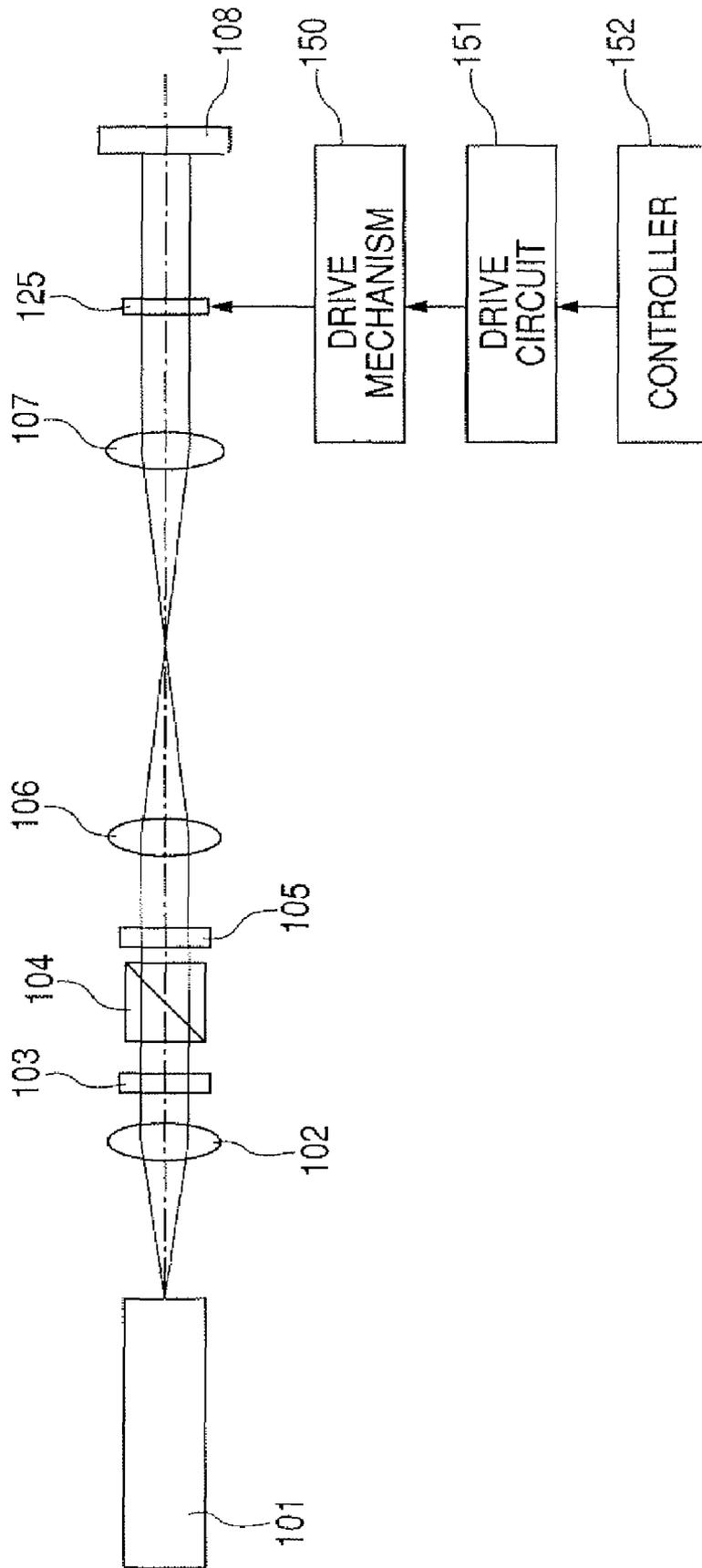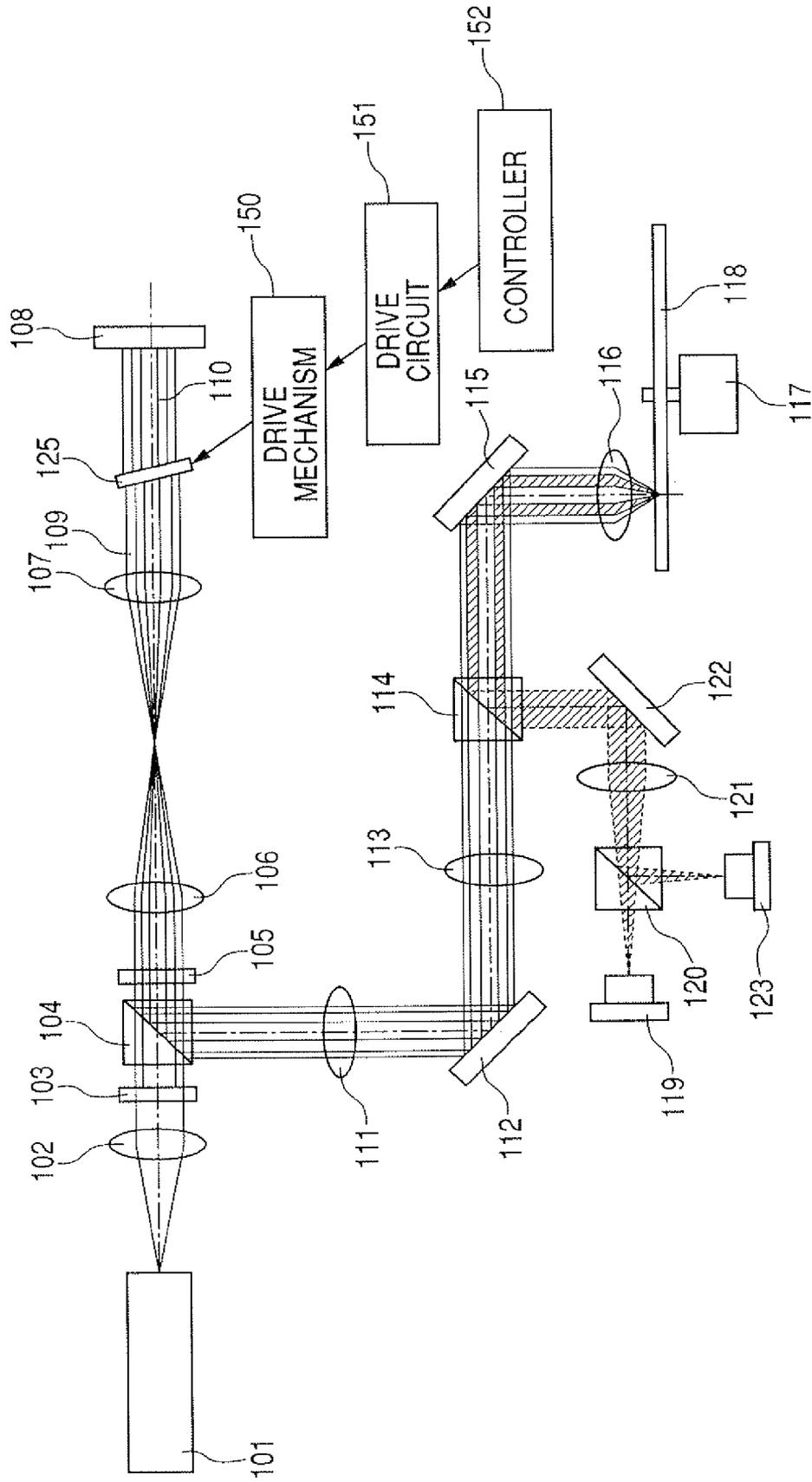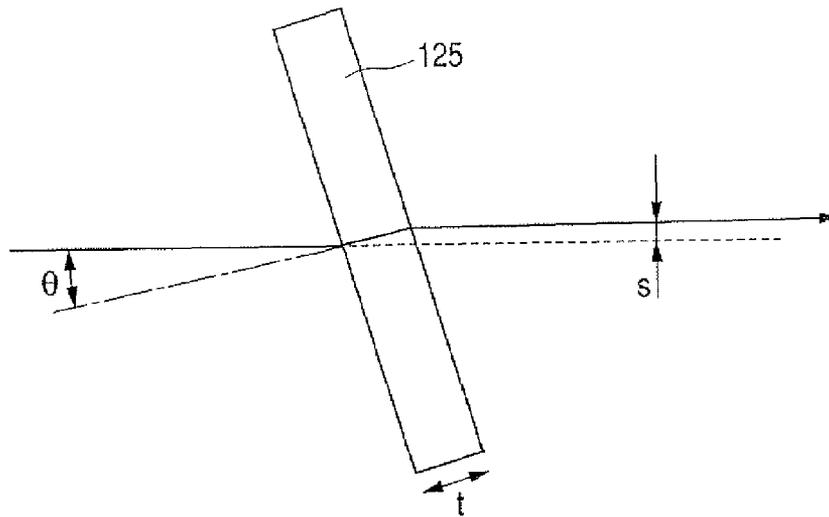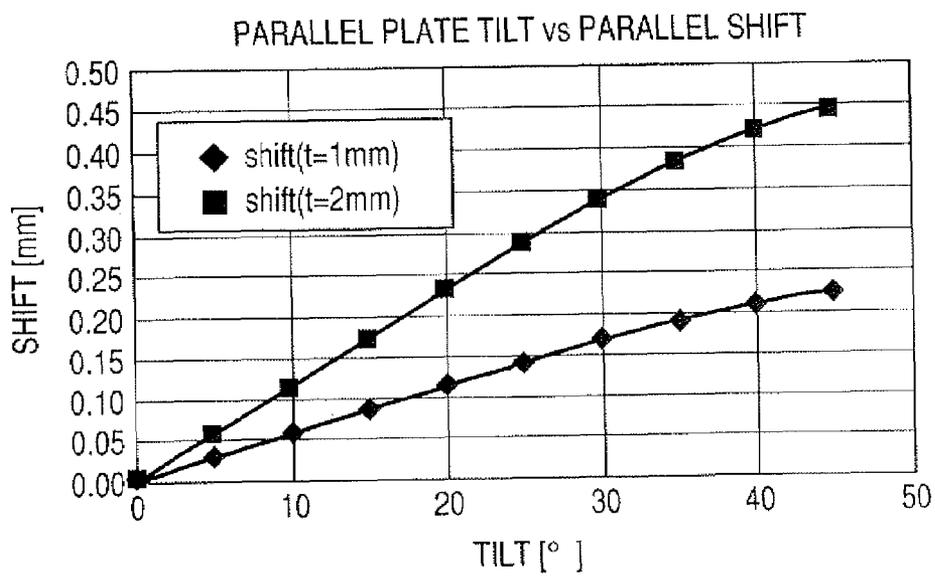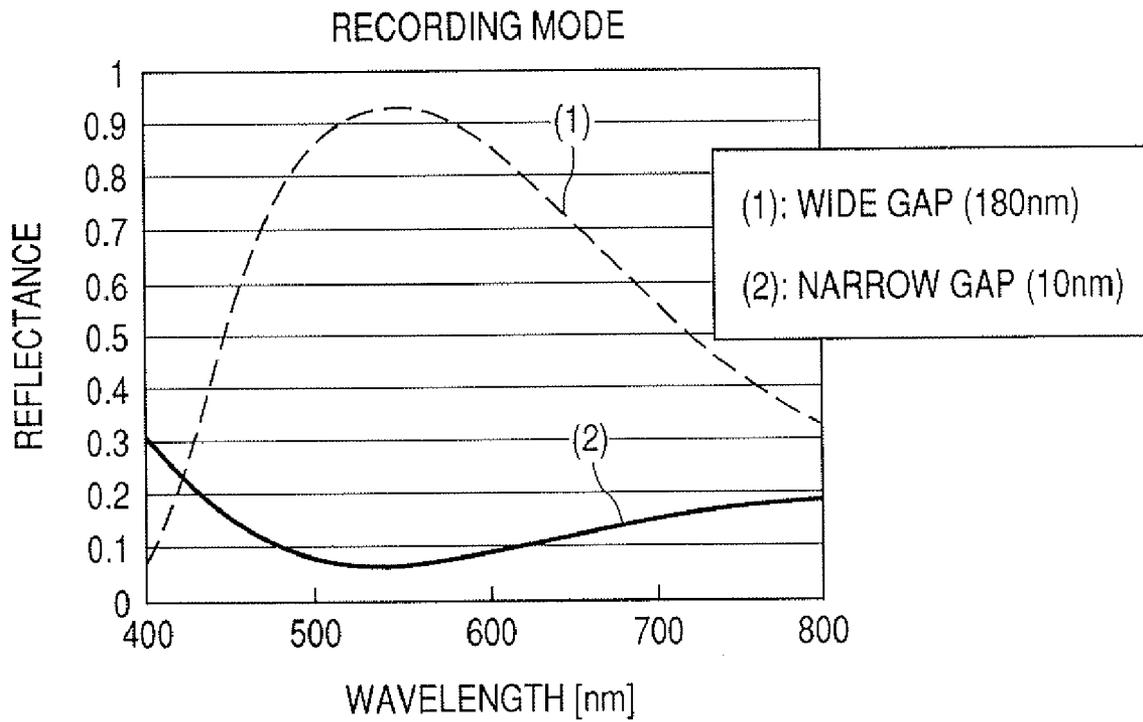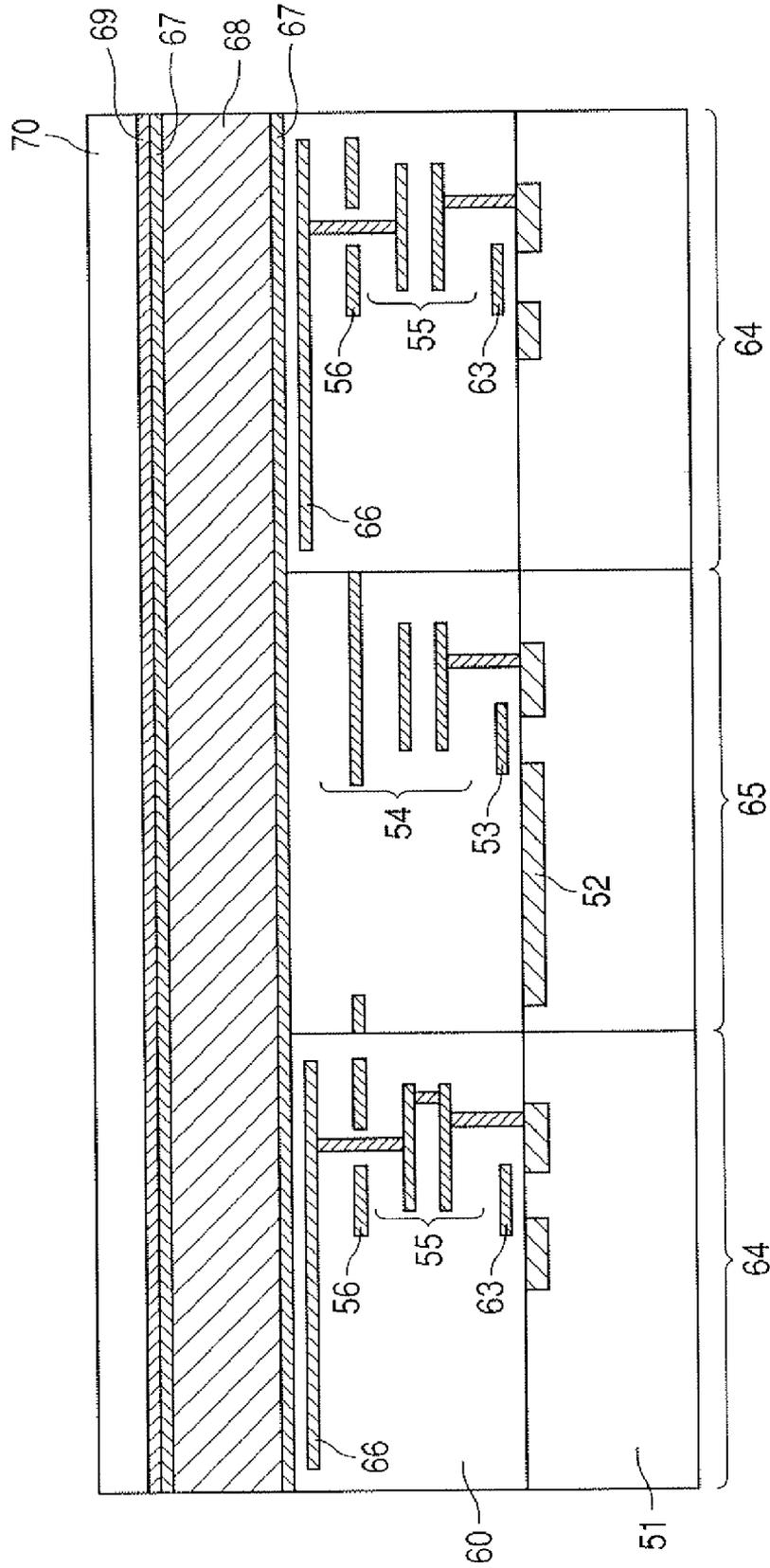
FIG. 20
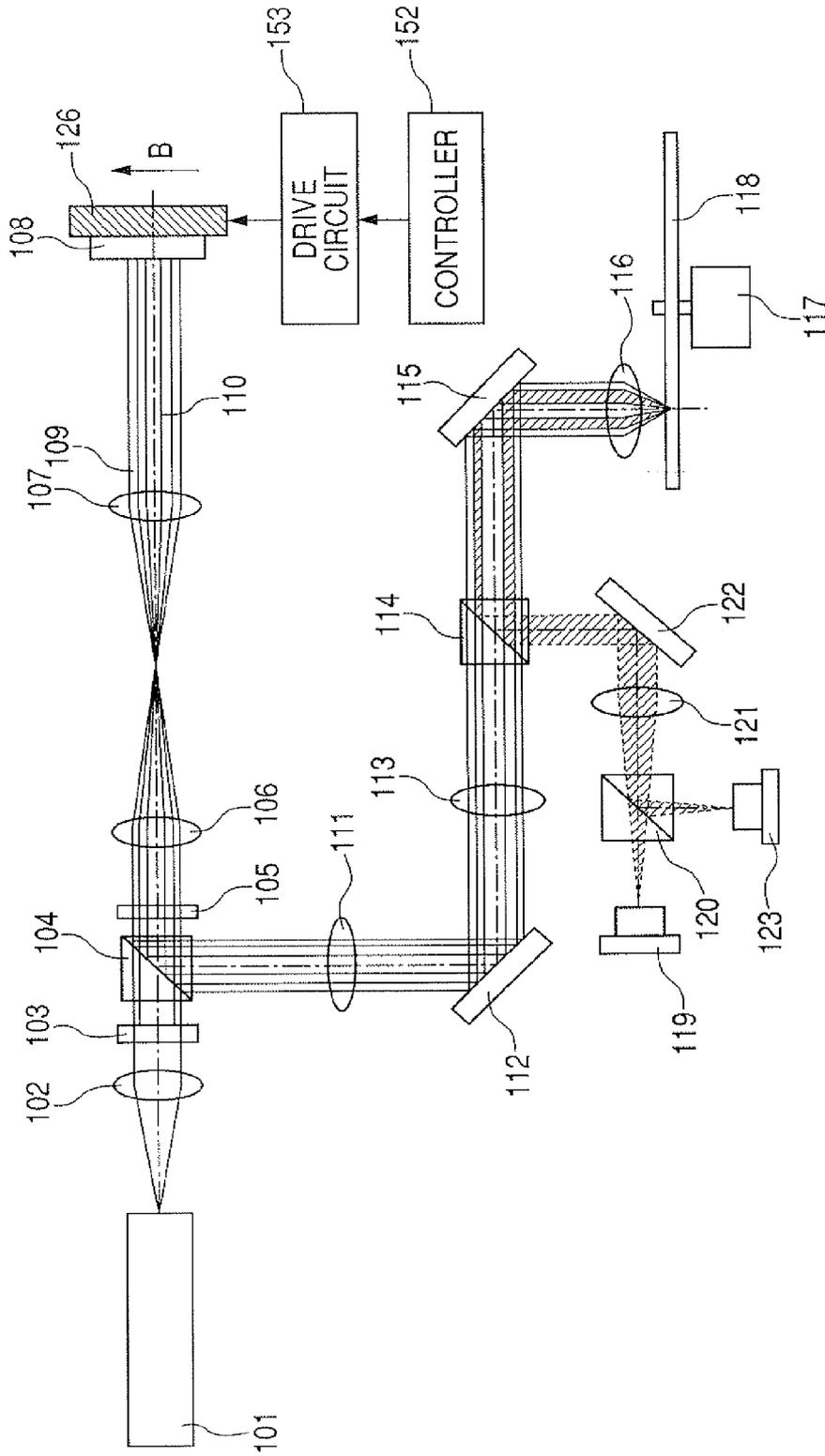
FIG. 21
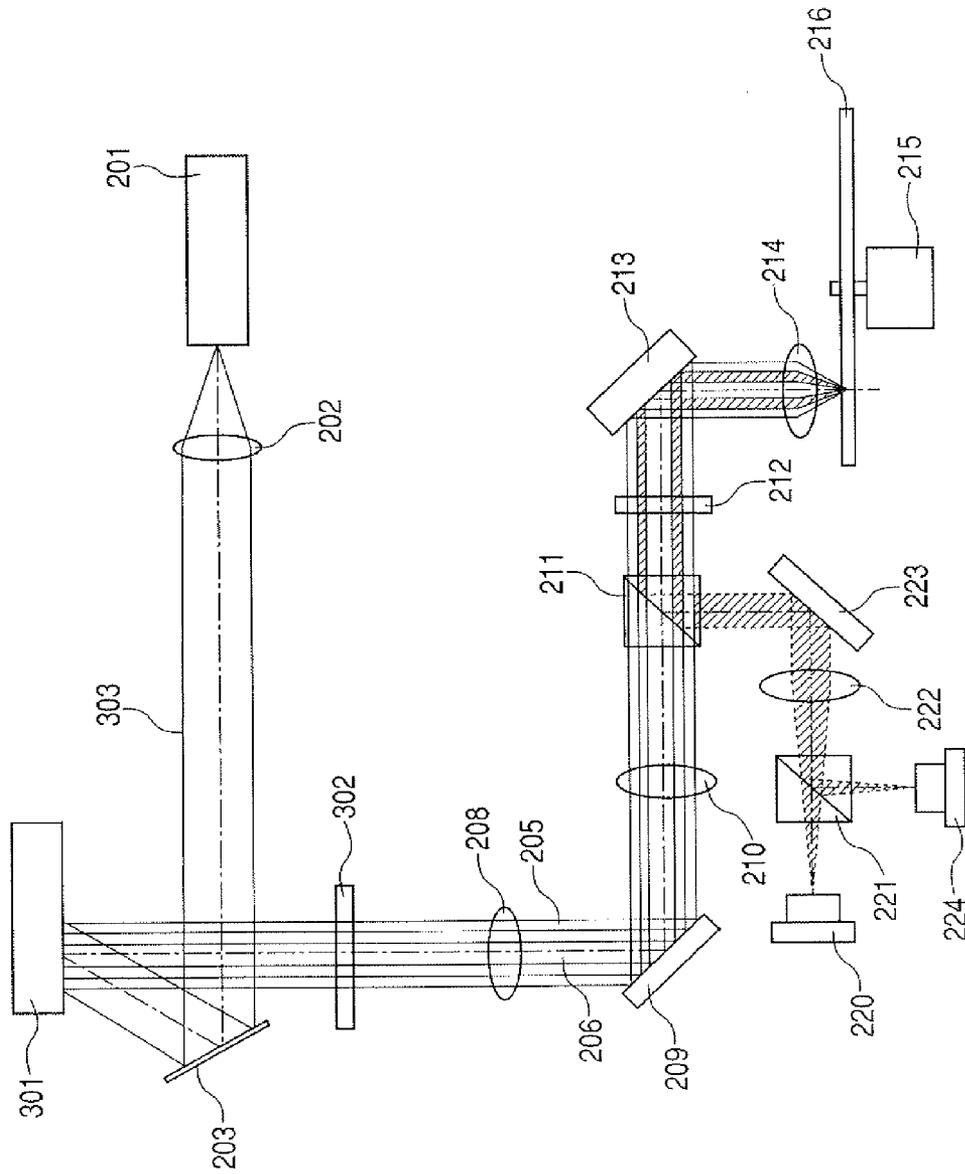
FIG. 22

FIG. 23

FIG. 24

FIG. 25

FIG. 26

RECORDING MODE

(1): WIDE GAP (180nm)

(2): NARROW GAP (10nm)
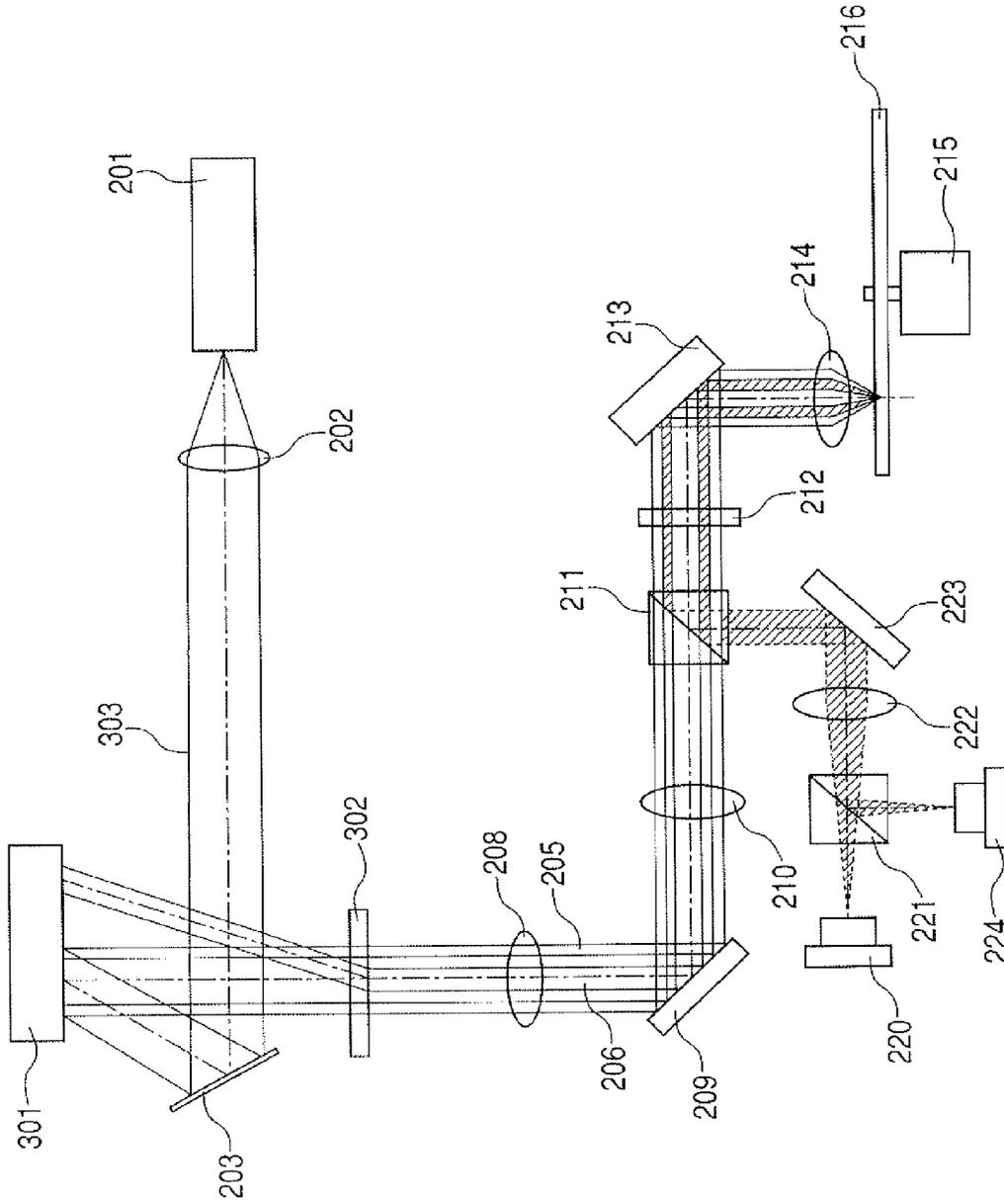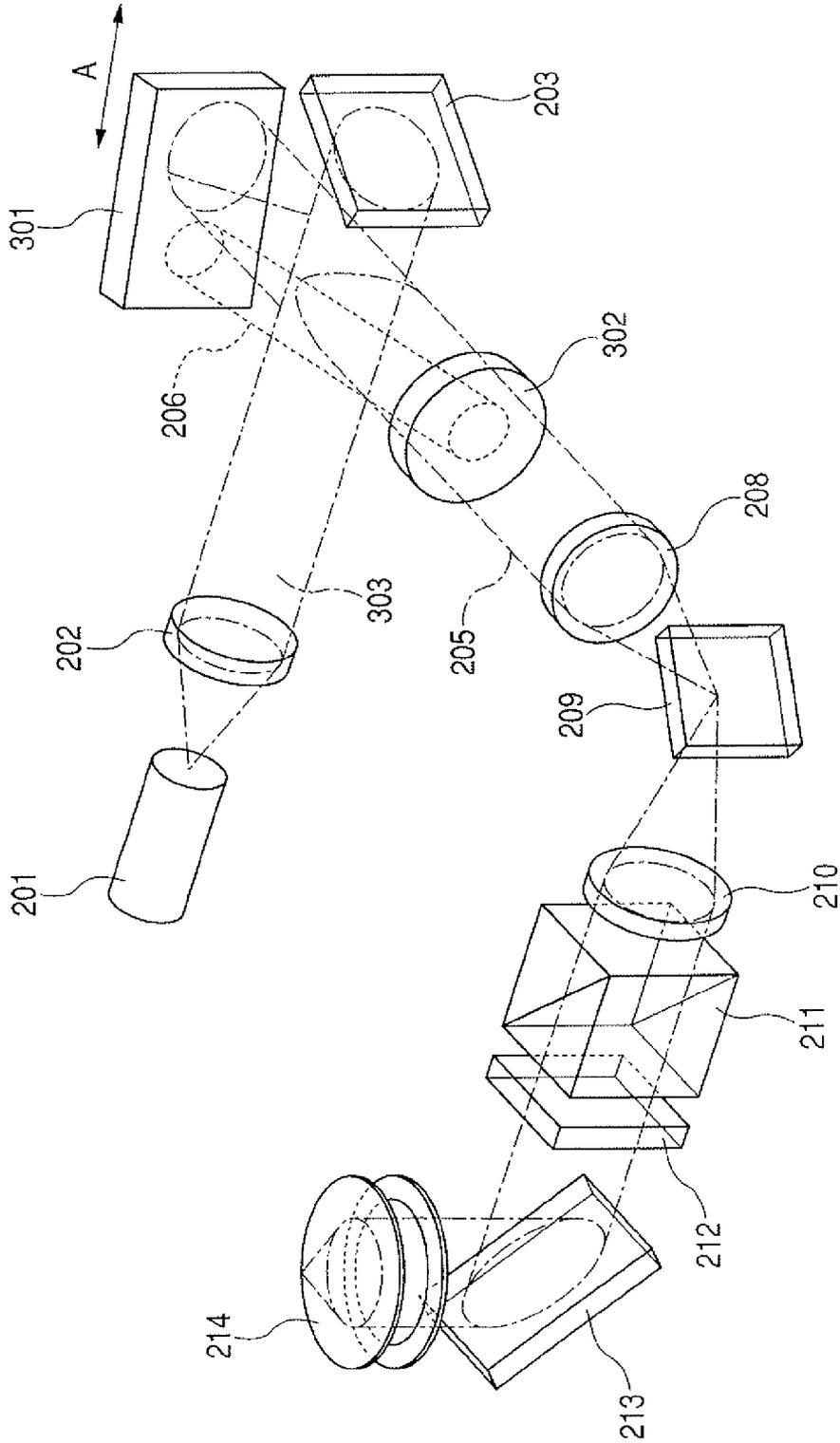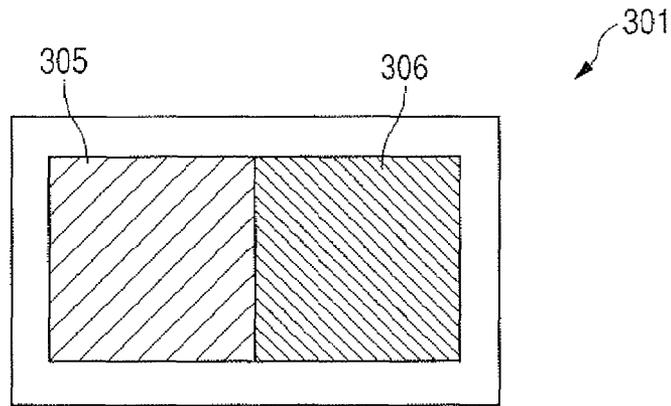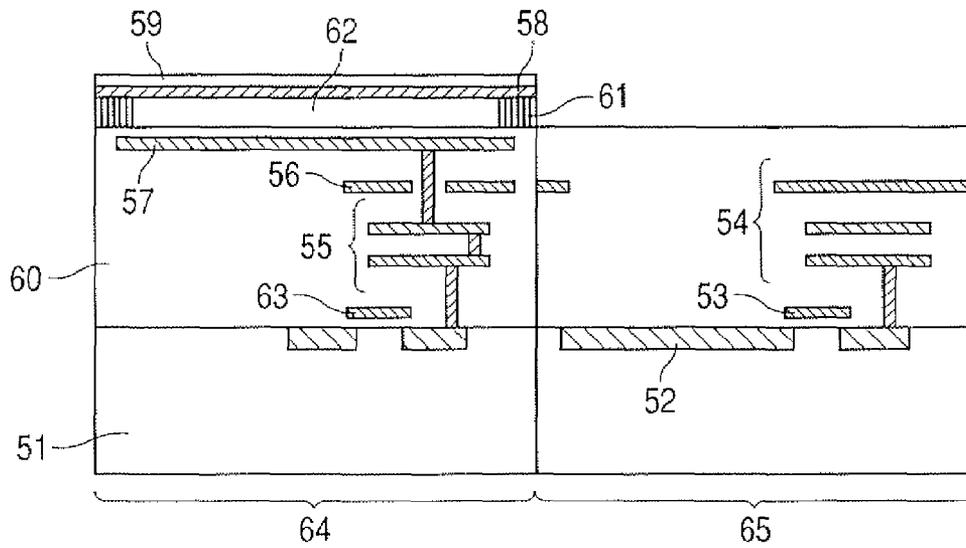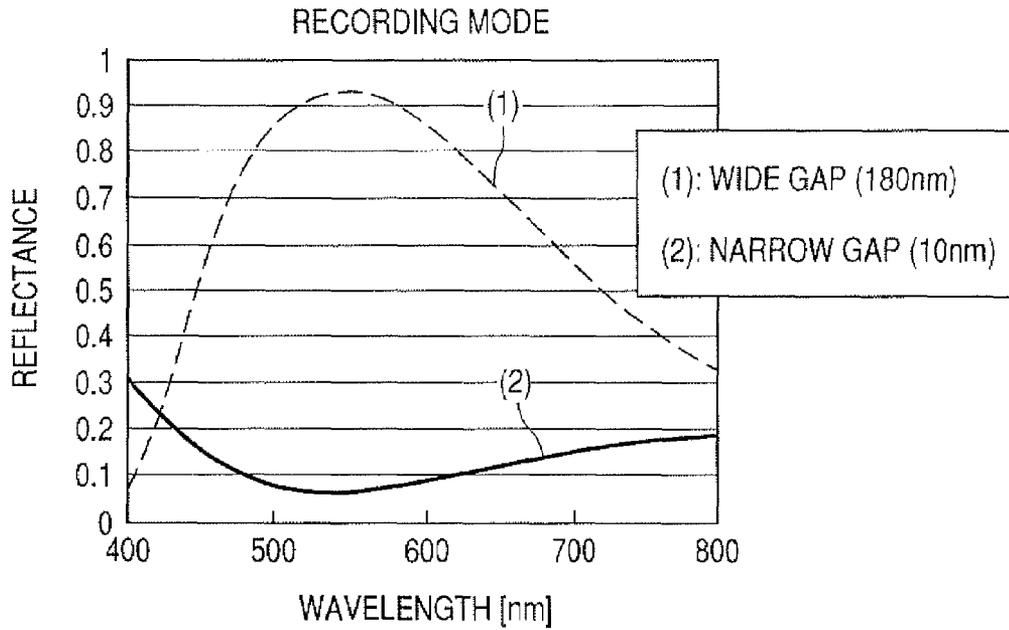
FIG. 27
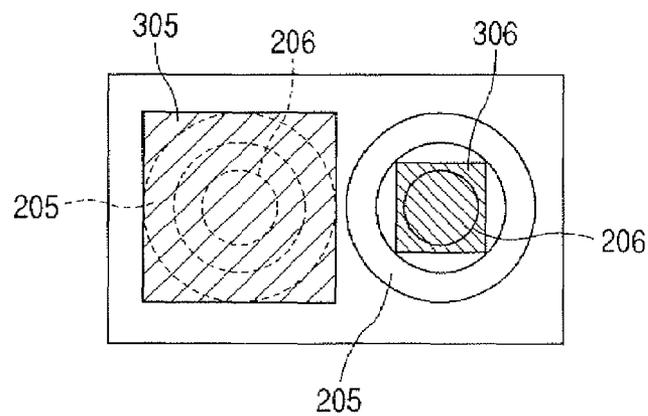
FIG. 28
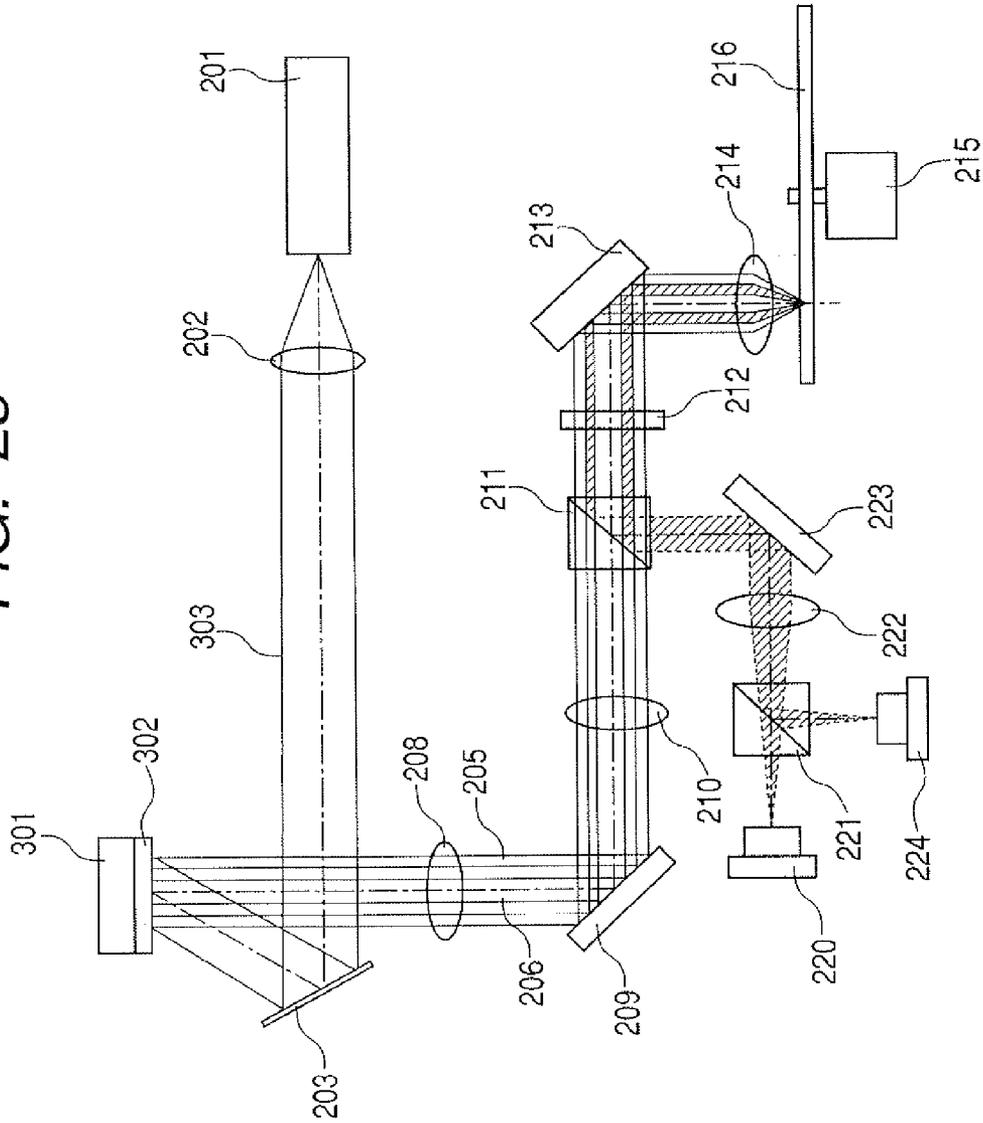
FIG. 29
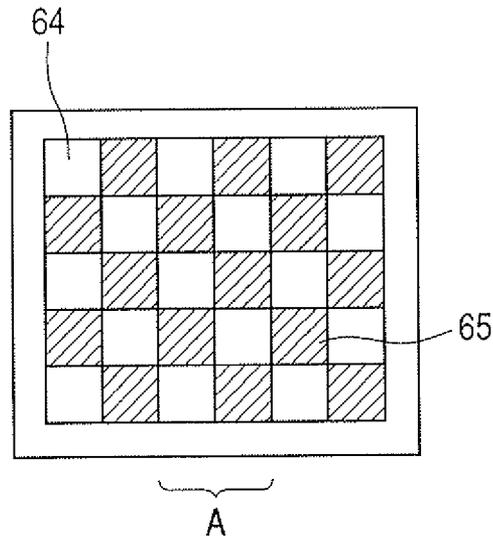
FIG. 30
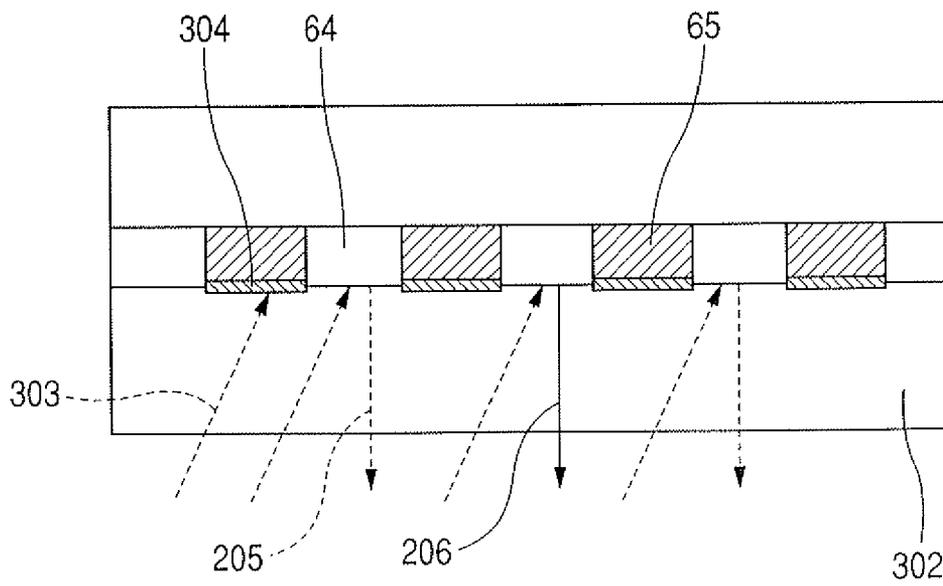
FIG. 31
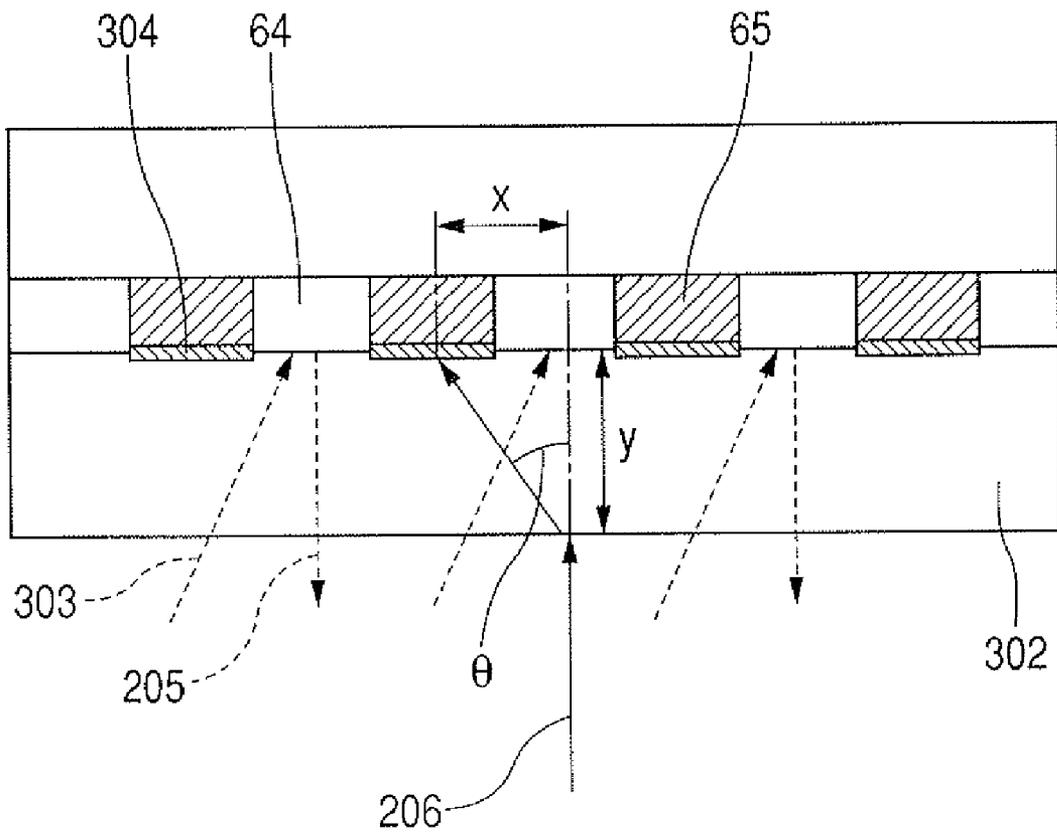
FIG. 32A
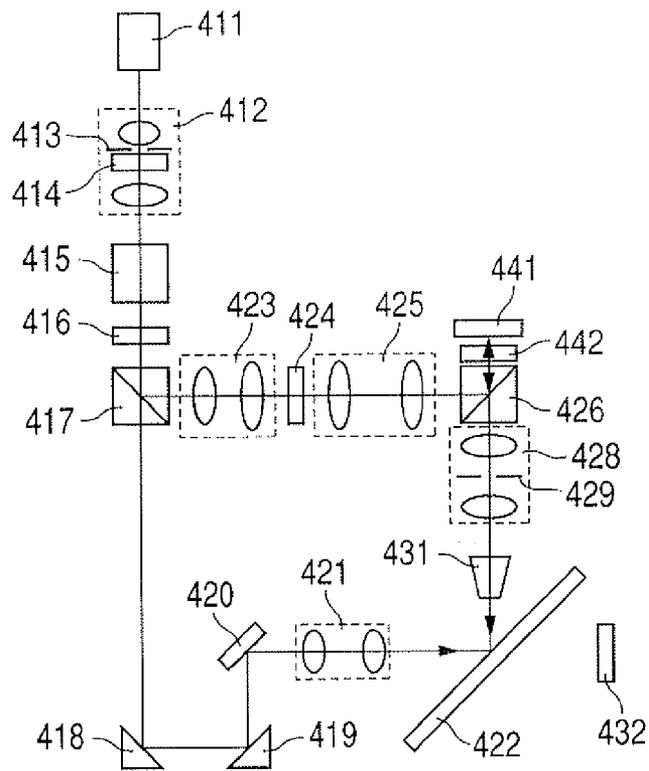
FIG. 32B
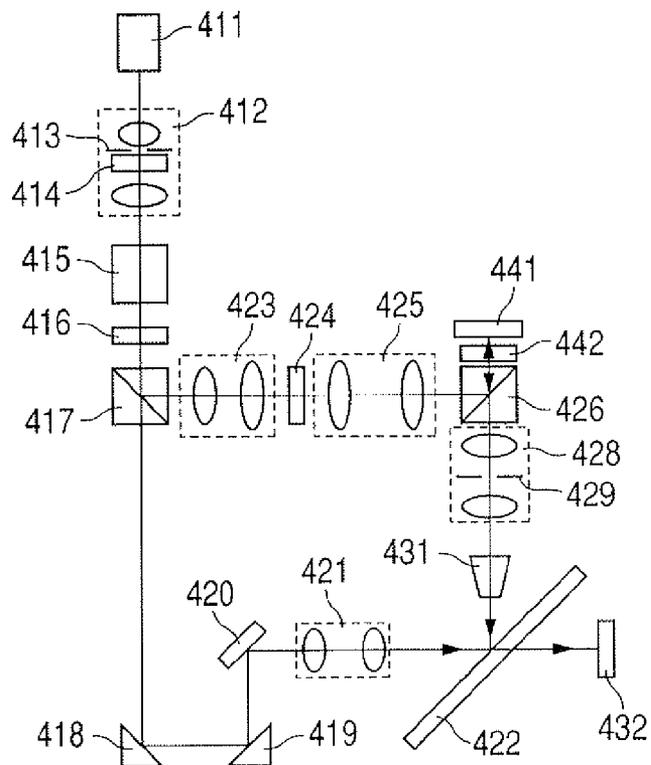
FIG. 33
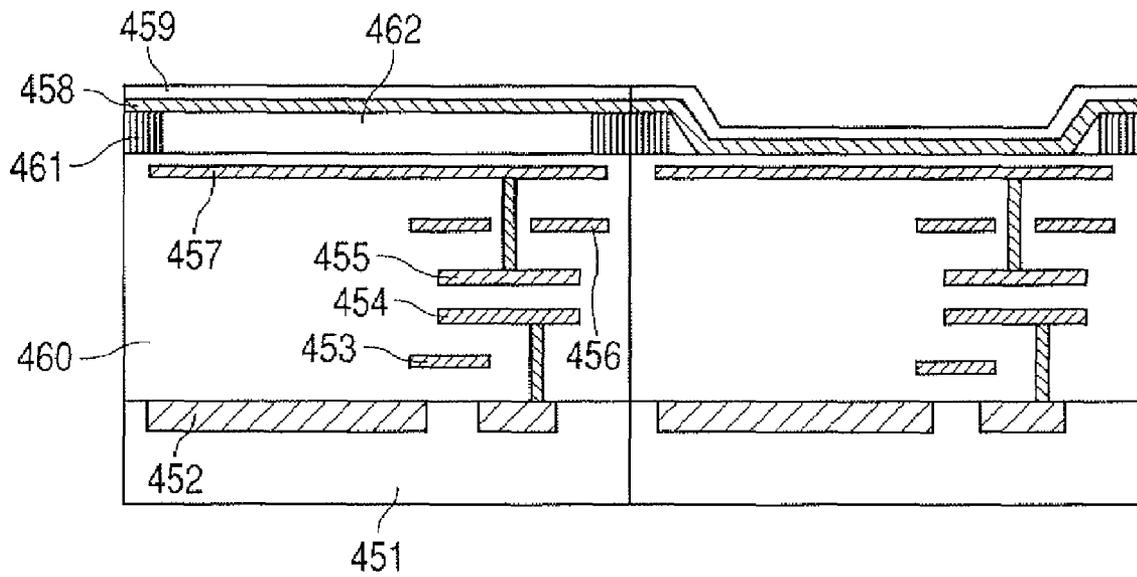
FIG. 34
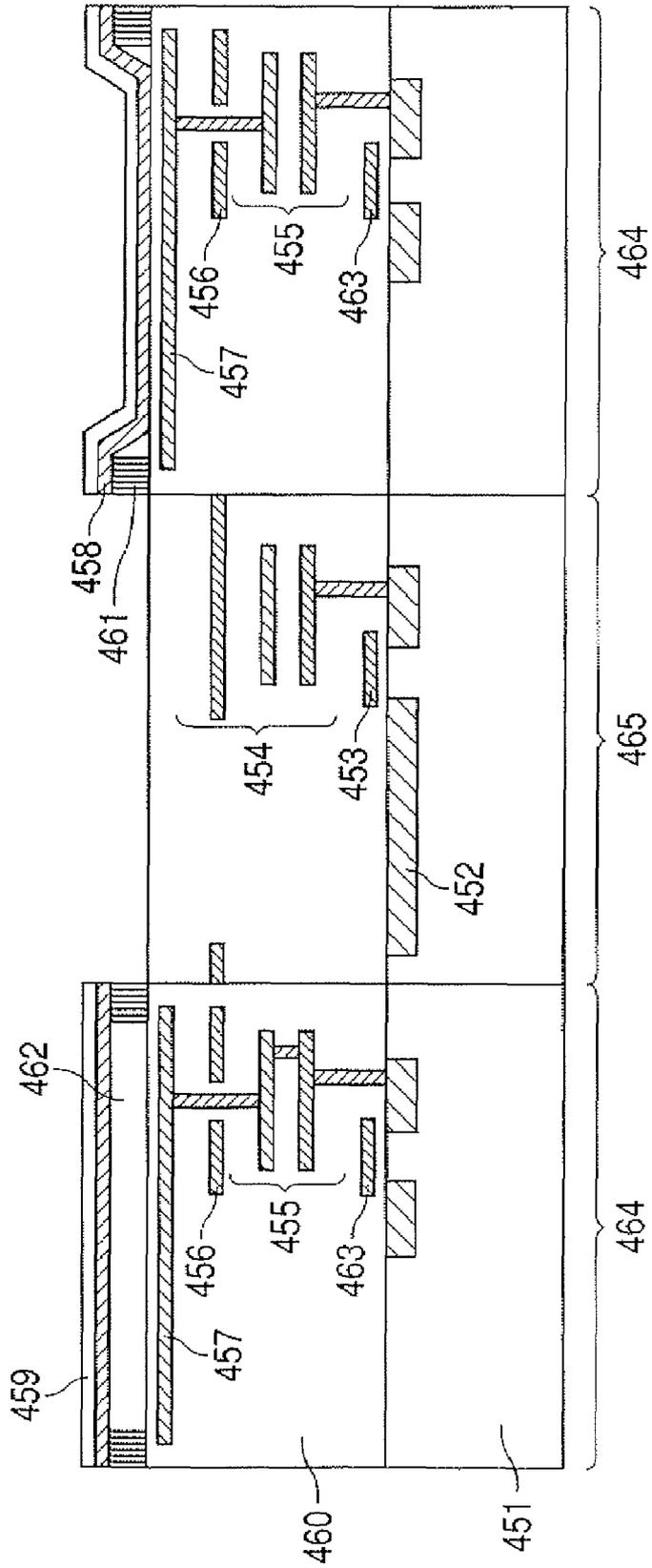
FIG. 35A
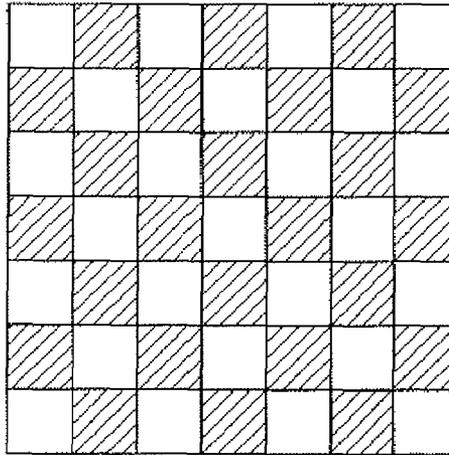
FIG. 35B
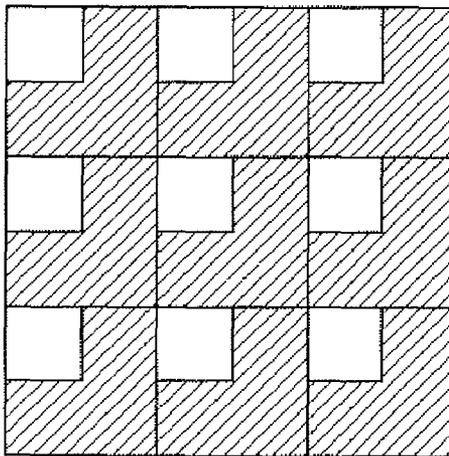
FIG. 35C
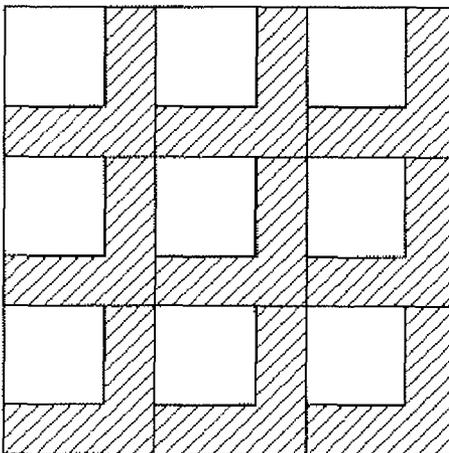
FIG. 36A
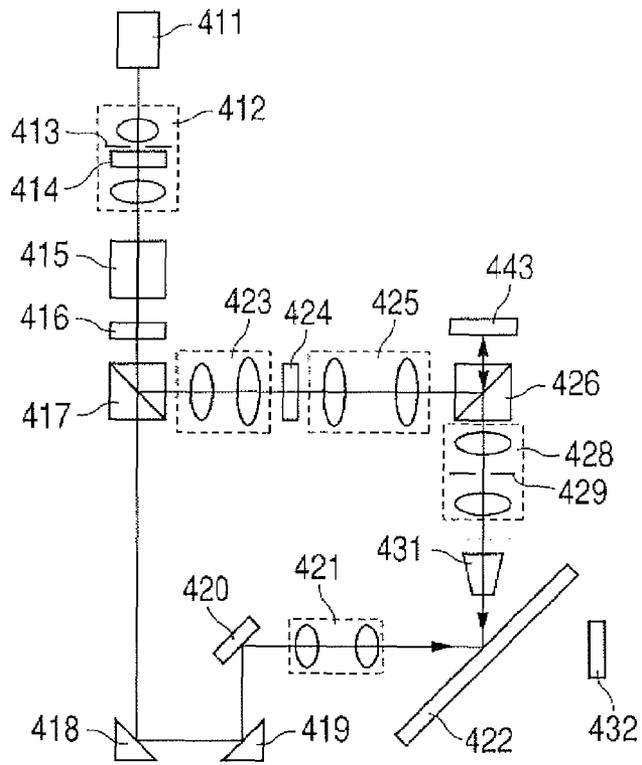
FIG. 36B

FIG. 37

FIG. 38

FIG. 39
PRIOR ART

FIG. 40B
PRIOR ART

FIG. 40A
PRIOR ART
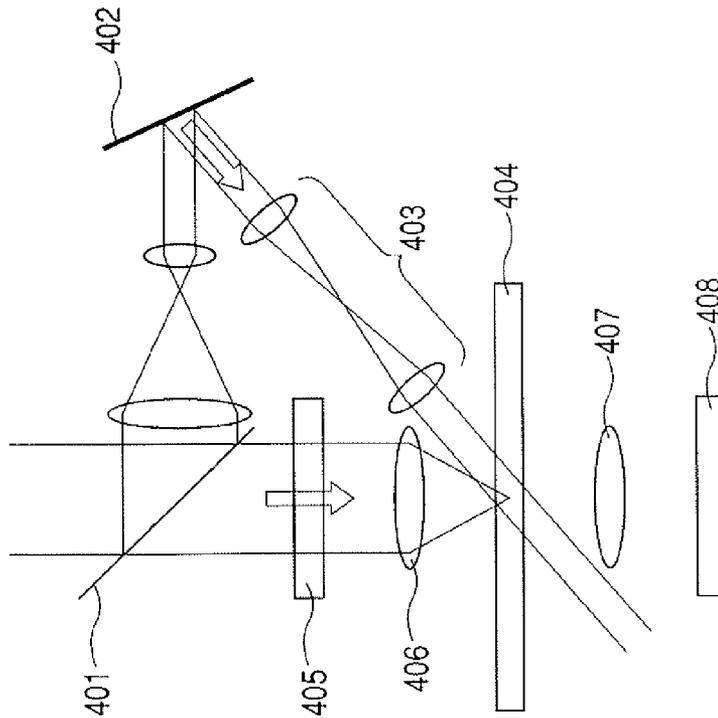
FIG. 41A
PRIOR ART

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FIG. 41B
PRIOR ART

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OPTICAL INFORMATION RECORDING AND REPRODUCING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an optical information recording and reproducing apparatus, and more particularly, to an optical information recording and reproducing apparatus for recording information with respect to a recording medium on which information is recorded using holography, and for reproducing information from the recording medium having information recorded thereon.

2. Description of the Related Art

FIG. 39 is a block diagram showing an optical system of a conventional coaxial type (collinear type) holographic memory.

First, a description is given on a case where information recording is performed with respect to a hologram disk 216 serving as a recording medium.

A light beam outputted from a green laser 201 of a light source is collimated by a collimator 202, and irradiates a spatial light modulator SLM 204 via a mirror 203.

In FIG. 39, a deformable mirror device (DMD) is used for the SLM 204.

Light reflected by a pixel representing the information "1" on the SLM 204 is reflected to the hologram disk 216, and light reflected by a pixel representing the information "0" is not reflected to the hologram disk 216.

Provided on the collinear SLM 204 are a portion for modulating an information light 206 and a portion for modulating a reference light 205 surrounding the information light 206 in an annular shape.

The reference light 205 and the information light 206 reflected by the pixel representing the information "1" on the SLM 204 are transmitted through a polarizing beam splitter PBS 207 as P-polarized light. After that, the reference light 205 and the information light 206 become incident upon the hologram disk 216 via a relay lens (1) 208, a mirror 209, a relay lens (2) 210, and a dichroic BS 211.

The reference light 205 and the information light 206 transmitted through a quarter wavelength plate QWP 212 and converted to circular polarized light (e.g., clockwise circular polarized light) are reflected by a mirror 213 to be incident upon an objective lens 214 with a focal distance f.

A pattern displayed on the SLM 204 by two relay lenses (1) and (2) forms an intermediate image at a distance f before the objective lens 214.

Thus, a so-called 4f optical system is configured, in which a pattern image (not shown) on the SLM, the objective lens 214, and the hologram disk 216 are placed with an interval f from each other.
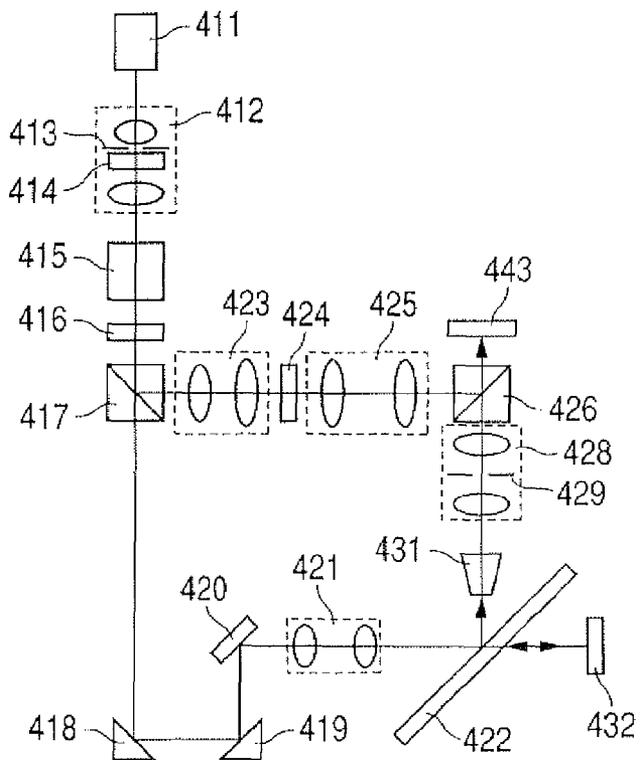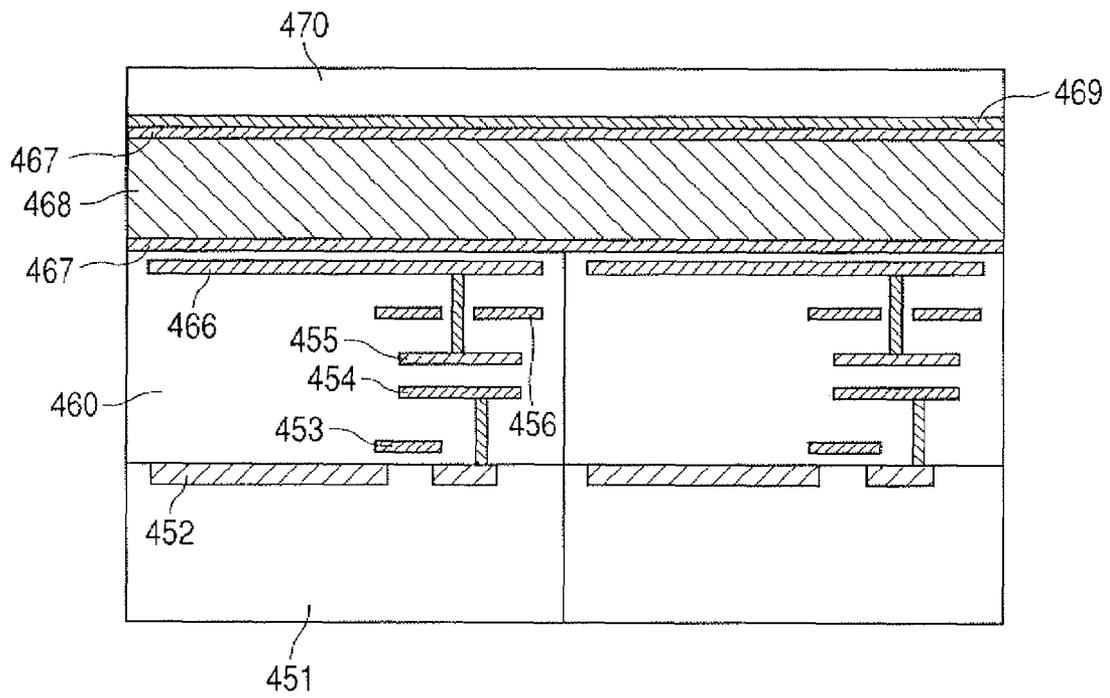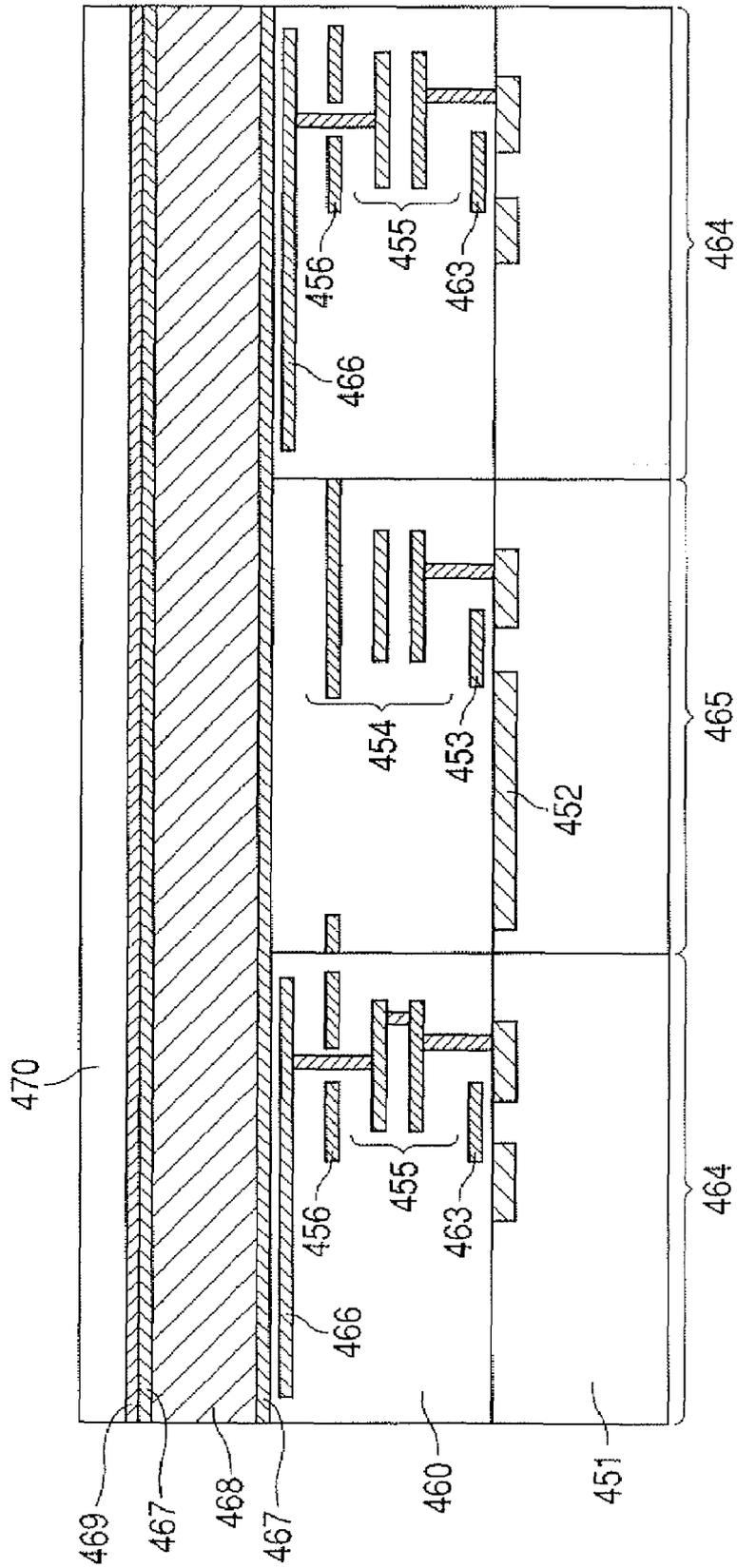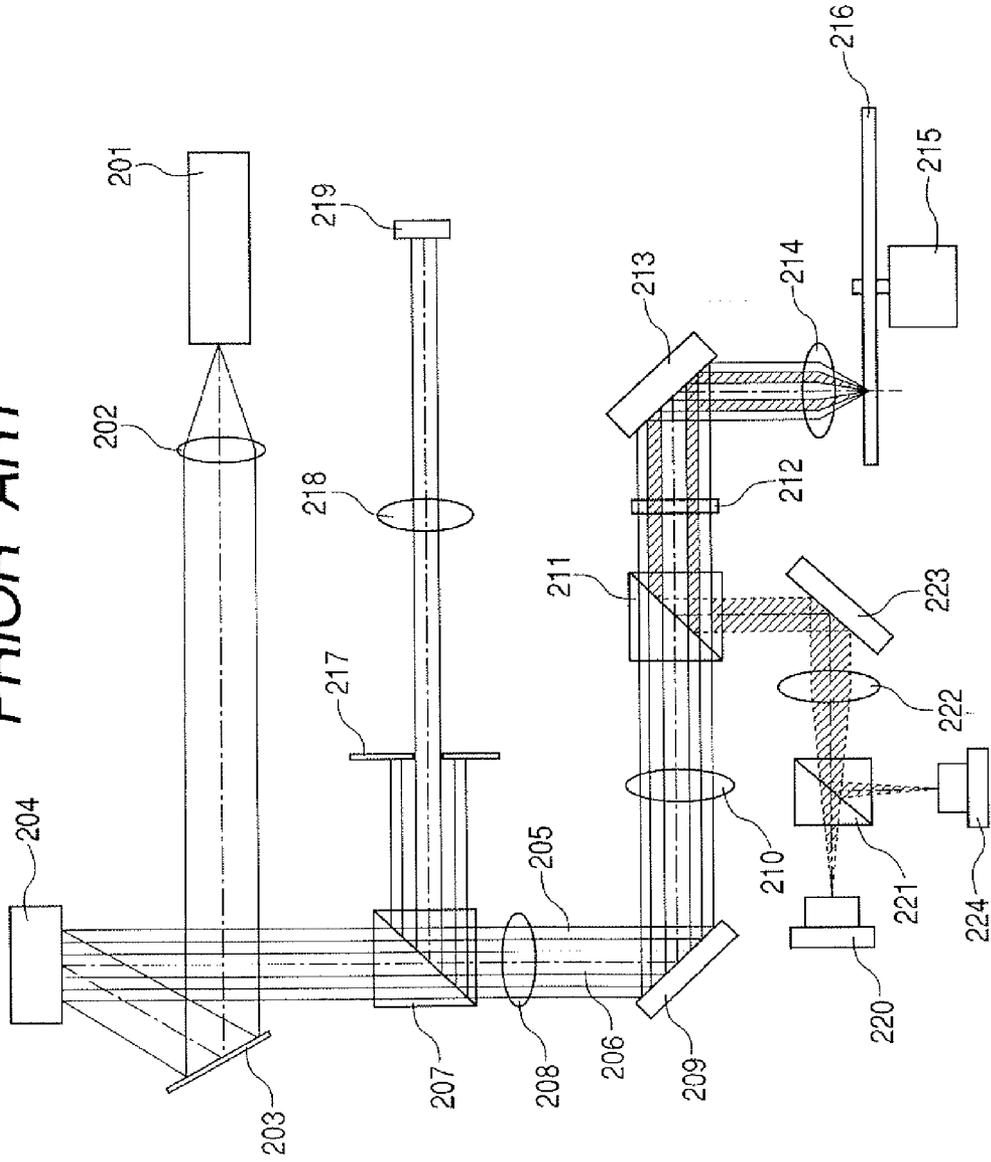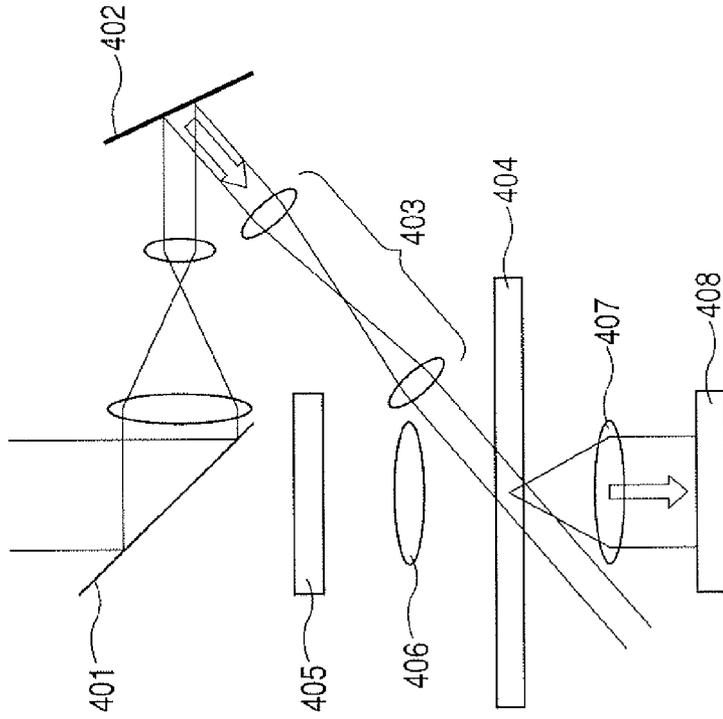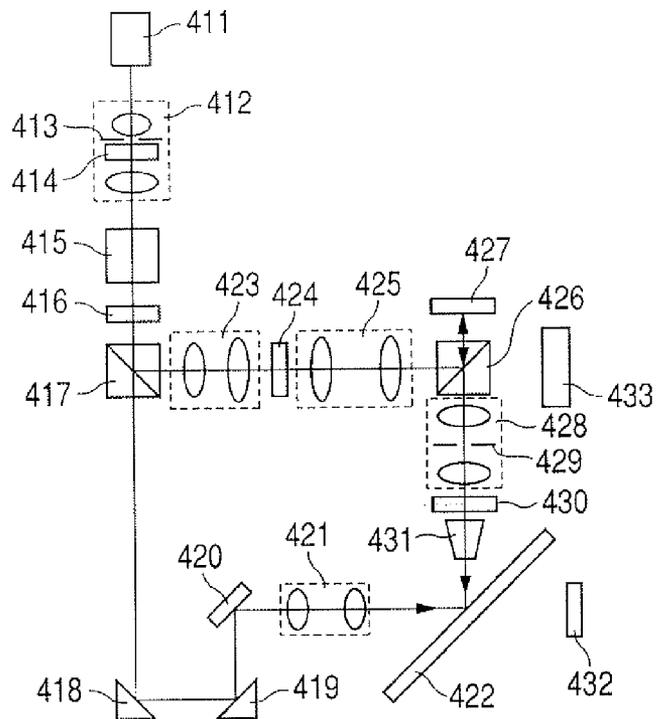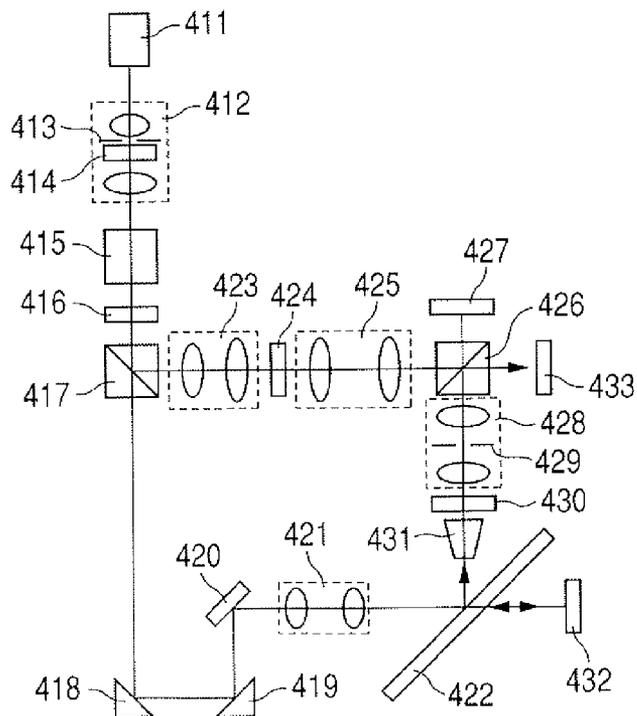
The hologram disk 216 has a disk shape and is rotatably held on a spindle motor 215.

The reference light 205 and the information light 206 are condensed onto a recording medium (not shown) on the disk by the objective lens 214 and interfere with each other to form an interference fringe.

On a polymer material in a recording medium, an interference fringe pattern during this recording is recorded as a refractive index distribution, and a digital volume hologram is formed. Further, in the recording medium, a reflective film is provided.

A red laser 220 which has no effect on the photosensitivity of the recording medium is provided, in addition to a green laser 201 for performing recording and reproduction with respect to a hologram, whereby a displacement of the holo-

gram disk 216 can be detected with high precision, with the above-mentioned reflective film being a reference surface.

As a result, even when axial deflection and radial runout occur in the hologram disk 216, a recording spot can be allowed to follow the recording medium surface dynamically using an optical servo technique, and an interference fringe pattern can be recorded with high precision.

The above-mentioned aspect will be described briefly below.

A linear polarized light beam outputted from the red laser 220 is transmitted through a beam splitter BS 221, and collimated by a lens 222. After that, the light beam is reflected by a mirror 223 and the dichroic BS 211, and travels to the hologram disk 216.

The light beam transmitted through the quarter wavelength plate QWP 212 and converted into circular polarized light (e.g., clockwise circular polarized light) is reflected by the mirror 213 to be incident upon the objective lens 214. After that, the light beam is condensed as a minute optical spot on a reflective surface of the hologram disk 216.

The reflected light beam becomes reverse circular polarized light (e.g., counterclockwise circular polarized light), and is incident upon the objective lens 214 again to be collimated. After that, the collimated light beam is reflected by the mirror 213, transmitted through the quarter wavelength plate QWP 212, and converted into a linear polarized light beam perpendicular to a forward path.

The light beam reflected by the dichroic BS 211 passes through the mirror 223 and the lens 222 in the same way as in the forward path, and is reflected by the beam splitter BS 221 to be guided to a photodetector 224.

The photodetector 224 has a plurality of light receiving surfaces (not shown) and can detect positional information on a reflective surface by a known method. Based on the detected positional information, the photodetector 224 can perform focusing and tracking of the objective lens 214.

Next, a case where recorded information is reproduced from the hologram disk 216 serving as a recording medium by using the above-mentioned optical system will be described.

The light beam outputted from the green laser 201 of a light source irradiates the spatial light modulator SLM 204 in the same way as in recording. During reproduction, only a portion modulating the reference light 205 on the SLM 204 represents the information "1", and a portion modulating the information light 206 displays information "0".

Thus, only a part of the reference light reflected by a pixel is reflected to the hologram 216, and the information light is not reflected to the hologram 216.

In the same way as in recording, the reference light 205 becomes circular polarized light (e.g., clockwise circular polarized light) to be condensed onto a recording medium (not shown) on a disk, and reproduces information light from the recorded inference fringe. The information light reflected by the reflective film in the recording medium becomes reverse circular polarized light (e.g., counterclockwise circular polarized light), and becomes incident upon the objective lens 214 again to be collimated. After that, the collimated light is reflected by the mirror 213, transmitted through the quarter wavelength plate QWP 212, and converted into a linear polarized light beam (S-polarized light) perpendicular to the forward path. At this time, an intermediate image of a display pattern of SLM reproduced at a distance f from the objective lens 214 is formed.

The light beam transmitted through the dichroic BS 211 is directed to the polarizing beam splitter PBS 207 via the relay lens (2) 210, the mirror 209, and the relay lens (1) 208.

The light beam reflected by the PBS forms an image again as an intermediate image of a display pattern of SLM at a position conjugate to the spatial light modulator SLM **204** by the relay lenses (**2**) and (**1**).

At this position, an aperture **217** is previously placed, and unnecessary reference light in the periphery of the information light is blocked. Through the lens **218**, the re-formed intermediate image forms an SLM display pattern only of a portion of the information light on a complementary metal oxide semiconductor (CMOS) sensor **219**. Consequently, unnecessary reference light is not incident upon the CMOS sensor **219**, so a reproduced signal with a satisfactory S/N can be obtained.

Regarding the above-mentioned technology, the following document is referred to: "Measurement and Nano-control Technology Supporting Holographic Memory/HVD™" (Proceeding of 35th Meeting on Lightwave Sensing Technology (LST35-12) June, 2005, Shochi Tan and Hideyoshi Horigome).

As described above, in the collinear holographic memory, information light and reference light can perform recording and reproduction in the coaxial optical arrangement having no angles, using one objective lens. Therefore, compared with a two-axis two-light beam interference system, an optical system is simplified.

Further, owing to the medium configuration with a reflective film, an optical system can be arranged on one side of a disk.

However, it is necessary to align the shift, tilt, and rotation of the two-dimensional spatial light modulator SLM **204** and the CMOS sensor **219** with high precision, which makes it difficult to decrease cost.

Further, a relay lens system used for an optical system projects the pattern of the spatial light modulator SLM **204** onto the CMOS sensor **219** exactly, so an expensive lens with a reduced distortion aberration and a reduced field curvature is required.

On the other hand, as another holographic memory, there is a system of recording a hologram on a recording medium by allowing two light beams to interfere with each other, as shown in FIGS. **40**A and **40**B.

FIGS. **40**A and **40**B show systems at a time of recording and reproduction, respectively.

During recording, a light beam is divided into two light beams by a beam splitter (BS) **401**. One of the light beams is allowed to be incident upon a recording medium **404** at a predetermined angle via a galvanometer mirror **402** and relay lenses **403** as reference light, and the other light beam divided by the BS **401** is modulated to a two-dimensional pattern in accordance with information by a spatial light modulator SLM **405** to be incident upon the recording medium **404** by an objective lens **406** as information light. Thus, the two-dimensional pattern modulated by the SLM **405** is formed on the recording medium **404** as an interference pattern, and recorded thereon. Then, the incident angle with respect to the recording medium **404** is changed by the galvanometer mirror **402**, whereby multi-recording in accordance with the angle is performed.

During reproduction, a light beam traveling to the SLM **405** and the objective lens **406** is blocked, and the recording medium **404** is irradiated with only the above-mentioned reference light at a predetermined angle, whereby a diffracted light by a hologram formed in the previous recording is generated. The diffracted light is condensed by an objective lens **407** for detection to form an image on a CMOS sensor **408**, and the information on the two-dimensional pattern formed by the SLM **405** during recording is reproduced.

However, according to the above-mentioned configuration, an optical system and the like are arranged on both sides of a recording medium, so there is a problem that an apparatus is enlarged. In order to solve the problem, an apparatus in which an optical system and the like are arranged on one side of the recording medium has been proposed so as to miniaturize the apparatus.

An example thereof is described in 2006 Optical Data Storage Topical Meeting Conference Proceedings MA1 "The InPhase Professional Archive Drive OMA: Design and Function" as shown in FIGS. **41**A and **41**B.

In the same way as the above, FIGS. **41**A and **41**B show apparatuses at a time of recording and reproduction, respectively.

First, the apparatus at a time of recording will be described.

Among light beams from a laser light source **411**, a light beam transmitted through a polarizing beam splitter PBS **417** becomes reference light, and is reflected by a mirror **418**, a mirror **419**, and a galvanometer mirror **420** to be guided to scanning lenses **421**. The scanning lenses **421** irradiate the guided reference light to a hologram recording medium **422**.

Herein, an expander **412** adjusts a light beam diameter to a desired diameter. A pin-hole **413** is a spatial filter for adjusting a wavefront. A shutter **414** is prepared for the purpose of controlling the exposure time during recording. An apodizer **415** is a filter for making the intensity distribution of a light beam uniform in a plane. A half wavelength plate **416** can rotate variably, and changes the polarized direction of a light beam incident upon the PBS **417** during reproduction described later so as to prevent light transmitted through the PBS **417** from being generated.

On the other hand, among the light beams from the laser light source, a light beam reflected by the PBS **417** is reflected by a PBS **426** to be incident upon a reflection type liquid crystal device **427**. The incident light beam has a polarized direction changed, and reflected while being two-dimensionally modulated in accordance with predetermined information to become information light. The generated information light is transmitted through the PBS **426**, and is irradiated to a hologram recording medium **422** by an objective lens **431**.

Herein, an expander **423** adjusts the diameter of a light beam to be information light. A phase mask **424** is a filter for eliminating the non-uniformity of an intensity distribution in the hologram recording medium on which the light beam is condensed by the objective lens. Relay lenses **425** superimpose a two-dimensional pattern image of the phase mask **424** on the reflection type liquid crystal device **427**. The relay lens **428** forms a two-dimensional pattern image of the reflection type liquid crystal device **427** on which the two-dimensional pattern image of the phase mask **424** is superimposed on an incident side focal plane of the objective lens **431**. A polytopic filter **429** is an aperture for restricting the mixing of reproducing light from outside of a desired hologram during hologram reproduction described later. A half wavelength plate **430** is capable of being switched, and is provided so as to change the polarized direction of a light beam from the hologram recording medium **422** during reproduction described later.

Next, the apparatus at a time of reproduction will be described.

During reproduction, the polarized direction of a light beam from the laser light source **411** is changed by the half wavelength plate **416**, whereby the light beam is prevented from being reflected by the PBS **417**. The light beam transmitted through the PBS **417** is reflected by the mirror **418**, the mirror **419**, and the galvanometer mirror **420**, and guided to the scanning lenses **421** to be irradiated to the hologram

recording medium **422** by the scanning lens. At this time, although a diffracted light by a hologram recorded on the hologram recording medium **422** is generated, the diffracted light is not used as information reproducing light.

The light beam transmitted through the hologram recording medium **422** is reflected by the galvanometer mirror **432**, and becomes incident upon the hologram recording medium **422** as reference light. The incident angle of the reference light with respect to the hologram recording medium **422** is controlled by the galvanometer mirror **420** and the galvanometer mirror **432**.

The reference light irradiated to the hologram recording medium **422** generates diffracted light by the hologram recorded on the hologram recording medium **422** to become information reproducing light. The information reproducing light is collected by the objective lens **431** and has its polarized direction changed by 90° by the half wavelength plate **430**, and furthermore, is incident upon the PBS **426** under the condition that information reproducing light other than the light corresponding to the reference light incident angle controlled by the galvanometer mirror **420** and the galvanometer mirror **432** is removed by the polytopic filter **429**. The light beam incident upon the PBS **426** has its polarized direction rotated by 90°, so it is reflected by the PBS **426** to be incident upon the CMOS sensor **433**.

Thus, two-dimensional pattern information corresponding to a desired hologram recorded on the hologram recording medium **422** is reproduced.

As described above, an apparatus in which an optical system and the like are arranged on one side of a recording medium (only the galvanometer mirror **32** is placed on the opposite side) is realized.

However, the above-mentioned conventional example has the following problem.

That is, regarding the reflection type liquid crystal device **427** and the CMOS sensor **433**, the relative shift, tilt, and rotation with respect to an optical axis are required to be aligned, which causes an increase in cost for adjusting an assembly. Further, the sizes of the reflection type liquid crystal device **427** and the CMOS sensor **433** are larger than those of a lens and the like that are the other constituent elements of the apparatus, which inhibits the miniaturization of the apparatus.

In view of the above-mentioned problems, it is an object of the present invention to alleviate the assembly adjustment precision regarding a spatial modulator and an image photodetector element and to further miniaturize an apparatus in a collinear system and a system to conduct recording by allowing two light beams to interfere with each other.

SUMMARY OF THE INVENTION

In view of the above, according to the present invention, a spatial light modulator SLM and a photodetector element CMOS sensor are placed on the same chip, and the alignment thereof and an expensive relay lens system are eliminated, whereby cost down and compacting of an optical system is achieved.

Specifically, there is provided an optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light, including:

a light source;

a spatial light modulator for generating at least an information light with respect to a light beam from the light source;

an objective lens for irradiating a recording medium with the light beam from the spatial light modulator; and

a photodetector element for receiving a reproduction light from the recording medium,

in which the spatial light modulator and the photodetector element are formed on a same semiconductor substrate.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing an optical system from a light source to a spatial light modulating/photodetector element during recording.

FIG. **2** is a block diagram showing an optical system from a spatial light modulating/photodetector element to a hologram disk during recording.

FIG. **3** is a block diagram illustrating an optical system during reproduction.

FIG. **4** is a detailed diagram of an optical arrangement shown in FIG. **1**.

FIG. **5** is a cross-sectional view of a light interference type spatial light modulating/photodetector element used in the present invention.

FIG. **6** illustrates an example of spectral reflectance characteristics of a light interference element.

FIG. **7** illustrates an example of spectral reflectance characteristics of a light interference element.

FIG. **8** is a detailed diagram of a liquid-crystal-on-silicon element in Embodiment 2.

FIG. **9** is a cross-sectional view of a reflection type liquid crystal element used in the present invention.

FIG. **10** is a block diagram showing Embodiment 3 of a collinear holographic memory optical system of the present invention.

FIG. **11** is a schematic diagram showing an optical system during recording (from a light source to an SLM) according to Embodiment 4 of the present invention.

FIG. **12** is a schematic diagram showing an optical system (from an SLM to a hologram memory medium) during recording according to Embodiment 4 of the present invention.

FIG. **13** is a schematic diagram showing an optical system during reproduction according to Embodiment 4 of the present invention.

FIG. **14** is a detailed diagram showing a parallel plate during reproduction according to Embodiment 4 of the present invention.

FIG. **15** is a graph showing a relationship between a tilt (θ) of a parallel plate and a shift amount (s) of a light beam according to Embodiment 4 of the present invention.

FIG. **16** is a cross-sectional view showing an integrated light interference type spatial light modulator and photodetector element (lateral arrangement) according to the present invention.

FIG. **17** is a diagram showing characteristics of a reflectance at a time of "1" and "0" of a light interference type SLM during recording according to Embodiment 4.

FIG. **18** is a cross-sectional view showing an integrated reflection type liquid crystal spatial modulating element and photodetector element (lateral arrangement) according to the present invention.

FIG. **19** is a diagram showing an in-plane arrangement of an integrated spatial light modulator and photodetector element (lateral arrangement) according to the present invention.

FIG. **20** is a schematic diagram showing an optical system during reproduction according to Embodiment 5.

FIG. **21** is a developed diagram showing an optical system in a recording operation according to Embodiment 6.

FIG. **22** is a developed diagram showing an optical system in a reproduction operation of an optical pickup apparatus according to Embodiment 6.

FIG. **23** is a perspective view in the case where an optical system of the optical pickup apparatus shown in FIG. **22** is actually arranged.

FIG. **24** is a plan view showing an SLM/CMOS used in Embodiment 6.

FIG. **25** is a cross-sectional view of an element in which a light interference type spatial modulating element and photodetector element CMOS sensor used in Embodiment 6 are arranged laterally.

FIG. **26** is a graph showing an example of spectral reflectance characteristics of an SLM/CMOS used in Embodiment 6.

FIG. **27** is a diagram showing a positional relationship in the case where a CMOS region of the SLM/CMOS according to Embodiment 6 is arranged in a region where information light is irradiated.

FIG. **28** is a developed diagram showing an optical system of an optical pickup apparatus according to Embodiment 7.

FIG. **29** is a diagram showing an SLM/CMOS used in Embodiment 7.

FIG. **30** is a cross-sectional diagram showing a state of the reference light and the information light during a recording operation of the SLM/CMOS configured integrally with a polarization hologram element used in Embodiment 7.

FIG. **31** is a cross-sectional diagram showing a state of the reference light and the information light during a reproduction operation of the SLM/CMOS configured integrally with a polarization hologram element used in Embodiment 7.

FIGS. **32**A and **32**B are diagrams each showing an optical path of an optical information recording and reproducing apparatus according to Embodiments 8 and 9.

FIG. **33** is a cross-sectional view (schematic view) of one pixel of an SLM/CMOS sensor element according to Embodiment 8.

FIG. **34** is a cross-sectional view (schematic view) of an SLM/CMOS sensor element according to Embodiment 9.

FIGS. **35**A, **35**B and **35**C are diagrams each showing an arrangement example of a spatial light modulating part and an image light receiving part according to Embodiments 9 and 11.

FIGS. **36**A and **36**B are diagrams each showing an optical path of an optical information recording and reproducing apparatus according to Embodiments 10 and 11.

FIG. **37** is a cross-sectional view (schematic view) of one pixel of an integrated SLM/CMOS sensor element according to Embodiment 10.

FIG. **38** is a cross-sectional view (schematic view) of an integrated SLM/CMOS sensor element according to Embodiment 11.

FIG. **39** is a diagram illustrating a conventional holographic memory (collinear system) of a coaxial type.

FIGS. **40**A and **40**B are diagrams each showing an optical path of a conventional two-light beam interference system.

FIGS. **41**A and **41**B are block diagrams each showing an optical system of a conventional two-light beam interference system has been proposed so as to miniaturize the apparatus.

DESCRIPTION OF THE EMBODIMENTS

Hereinafter, preferred embodiments for carrying out the present invention will be described with reference to the attached drawings.

Embodiment 1

FIGS. **1** to **7** illustrate Embodiment 1 of a collinear holographic memory optical system of the present invention.

FIG. **1** is a block diagram showing an optical system from a light source to a spatial light modulating/photodetector element during recording, and FIG. **2** is a block diagram showing an optical system from a spatial light modulating/photodetector element to a hologram disk during recording.

FIG. **3** is a block diagram illustrating an optical system during reproduction. FIG. **4** is a detailed diagram of an optical arrangement of FIG. **1**. FIG. **5** is a cross-sectional diagram of a light interference type spatial light modulating/photodetector element used in the present invention. FIGS. **6** and **7** each show an example of spectral reflectance characteristics of a light interference element.

First, the case where information is recorded on a hologram disk **118** that is a recording medium will be described with reference to FIGS. **1**, **2**, and **4**.

In FIG. **1**, a light beam emitted from a green laser **101** of a light source is collimated by a collimator **102** to be incident upon a mask element **103**.

The mask element **103** masks a portion corresponding to information light in a center portion of a light beam.

The mask element **103** is a liquid crystal element in this embodiment, but a mask covering a center portion may be inserted in an optical path. During recording, the mask element **103** does not function to transmit all the light beams.

The light beam transmitted through a polarizing beam splitter PBS **104** as P-polarized light is transmitted through a quarter wavelength plate QWP **105** provided as required.

After that, the light beam passes through a relay lens (A) **106** and a relay lens (B) **107**, and illuminates a spatial light modulating/photodetector element (hereinafter, referred to as an SLM/CMOS) **108** with a spatial light modulator SLM and a CMOS sensor mounted on one chip.

In the case of using a light interference modulating element with a configuration in which a polarized state is not changed as an SLM, the quarter wavelength plate QWP **105** may be provided previously.

Herein, a collinear holographic memory optical system of the present invention will be described with reference to FIG. **4**.

In FIG. **4**, an optical path from the green laser **101** to the SLM/CMOS **108** is represented by a dot and dash line.

The light beam collimated by the collimator **102** passes through the mask element **103**, the PBS **104**, and the quarter wavelength plate QWP **105** successively to be incident upon a relay lens system.

In this embodiment, the mask element **103** is a liquid crystal element, and has angle dependency with respect to incident light together with the PBS. Therefore, this configuration is preferable for obtaining a satisfactory S/N with the extinction ratio enhanced.

Since the relay lens (A) **106** and (B) **107** are provided with an interval of 2f with f being a focal distance, the light beam once forms an image between the relay lenses and is collimated by the relay lens (B) **107** again. The light beam incident upon the SLM/CMOS **108** is desirably collimated so as to enhance the optical efficiency.

On the other hand, an optical path from the mask element **103** to the SLM/CMOS **108** is represented by a dotted line. A mask image of the mask element **103** placed after the collimator **102** needs to be formed on the SLM/CMOS **108** so as to shield a required portion.

Because the mask element **103** is provided at the distance f from the relay lens (A) **106**, the mask image is formed on the SLM/CMOS **108** by the relay lens (B) **107**.

A front view of the SLM/CMOS **108** is shown in FIG. **4**.

On the SLM/CMOS **108**, a pattern **21** for reference light and a pattern **22** for object light are arranged on the same axis. The mask image **23** shields the pattern for object light during reproduction of information.

As described above, the collinear holographic memory optical system of the present invention collimates a light beam transmitted and reflected by the mask element, the PBS, and the SLM/CMOS **108**, and forms a mask element image on a modulating/photodetector element. The SLM/CMOS **108** will be described later in detail.

In FIG. **2**, the light beam reflected by the SLM/CMOS **108** and transmitted through the quarter wavelength plate QWP **105** is converted into circular polarized light (e.g., clockwise circular polarized light). After that, the light beam passes through the relay lens (A) **106** and the relay lens (B) **107** to be incident upon the SLM/CMOS **108**.

Light reflected by a pixel representing information "1 (white)" on the SLM is reflected to the hologram disk **118** with a high reflectance. Light reflected by a pixel representing information "0 (black)" is reflected in an only small amount to the hologram disk **118** due to interference.

In the same way as in a conventional example, provided on the collinear SLM are a portion for modulating an information light **110** and a portion for modulating a reference light **109** surrounding the information light **110** in an annular shape.

In FIG. **2**, the light beam reflected by the SLM/CMOS **108** becomes reverse circular polarized light (e.g., counterclockwise circular polarized light).

The light beam having passed through the relay lens (B) **107** and the relay lens (A) **106** is transmitted through the quarter wavelength plate QWP **105** to be converted into S-polarized light, and reflected by the PBS **104** to be outputted to the hologram disk **118**.

The reference light **109** and the information light **110** reflected by the pixel representing information "1 (white)" on the SLM of the SLM/CMOS **108** is reflected by the polarizing beam splitter PBS **104**.

After that, the light beam travels to the hologram disk **118** via a relay lens (1) **111**, a mirror **112**, a relay lens (2) **113**, and a dichroic BS **114**. After that, the light beam is reflected by a mirror **115** to be incident upon an objective lens **116** at the focal distance f.

A pattern displayed on the SLM of the SLM/CMOS **108** by the two relay lenses (1) and (2) forms an intermediate image at the position distance f before the objective lens **116**.

Consequently, a so-called 4f optical system is configured, in which a pattern image (not shown) on the SLM, the objective lens **116**, and the hologram disk **118** are placed at the distance f.

The hologram disk **118** has a disk shape, and is held on a spindle motor **117** rotatably. The reference light **109** and the information light **110** are condensed onto a recording medium (not shown) on the disk by the objective lens **116**, and interfere with each other to form an interference fringe.

On a polymer material in the recording medium, the interference fringe pattern during recording is recorded as a refrac-

tive index distribution, and a digital volume hologram is formed. Further, a reflective film is provided in the recording medium.

In the same way as in the conventional example, in addition to the green laser **101** for performing recording and reproduction of a hologram, a red laser **119** having no photosensitivity with respect to a recording medium is provided.

Consequently, the displacement of the hologram disk **118** can be detected with high precision, with the above-mentioned reflective film being a reference surface.

Owing to the above, even when axial deflection and radial runout occur in the hologram disk **118**, a recording spot can be allowed to follow the recording medium surface dynamically, using an optical servo technique, and an interference fringe pattern can be recorded with high precision.

A light beam emitted from the red laser **119** is transmitted through a beam splitter BS **120**, and collimated by a lens **121**. After that, the light beam is reflected by a mirror **122** and a dichroic BS **114**, and becomes incident upon the hologram disk **118**.

After that, the light beam is reflected by the mirror **115** to be incident upon the objective lens **116**, and condensed as a minute light spot on a reflective surface on the hologram disk **118**.

The reflected light beam becomes incident upon the objective lens **116** again to be collimated. After that, the light beam reflected by the mirror **115** and the dichroic BS **114** successively passes through the mirror **122** and the lens **121** in the same way as in the forwarding path, is partially reflected by the beam splitter BS **120**, and guided to a photodetector **123**.

The photodetector **123** has a plurality of light receiving surfaces (not shown) and can detect positional information on the reflective surface by a known method and perform focusing and tracking of the objective lens **116** based on the positional information.

Next, the case where recorded information is reproduced from the hologram disk **118** that is a recording medium will be described with reference to FIG. **3**.

A light beam emitted from the green laser **101** of a light source illuminates a spatial light modulator SLM **108**.

During reproduction, the mask element **103** has a function of masking a portion corresponding to information light in a center portion of a light beam.

A liquid crystal element of this embodiment rotates the polarized direction of only a center portion of a light beam by 90° to obtain S-polarized light, and reflects the S-polarized light by the PBS **104** so that the S-polarized light does not reach the SLM/CMOS **108**. Further, a mask shielding the center portion may be inserted in an optical path.

Two relay lenses (A) **106** and (B) **107** have a function of allowing an image of the mask element **103** to be formed on the SLM of the SLM/CMOS **108**, and only the portion of the element corresponding to the reference light is irradiated and that corresponding to the information light is shielded.

Only the portion for modulating the reference light **109** on the SLM/CMOS **108** displays information "1 (white)", and the portion for modulating the information light **110** displays information "0 (black)".

Thus, only the light reflected by a pixel in the portion of the reference light is reflected to the hologram disk **118**. A light beam of a pixel in the portion of the information light is not reflected to the hologram **118** as well as not irradiated, so information light with a better S/N compared with a conventional example can be reproduced.

In the same way as in recording, the reference light **109** is reflected by the PBS **104**, and condensed onto a recording

medium (not shown) on a disk to reproduce information light from a recorded interference fringe.

Information light reflected by the reflective film in the recording medium becomes incident upon the objective lens 116 again to be collimated, and reflected by the mirror 115. At this time, an intermediate image of the reproduced display pattern of the SLM is formed at the distance f from the objective lens 116.

The light beam transmitted through the dichroic BS 114 passes through a relay lens (2) 113, a mirror 112, and a relay lens (1) 111 to be incident upon the polarizing beam splitter PBS 104. The light beam is formed again as an intermediate image (not shown) of a display pattern of the SLM at a position conjugate to the mask element 104 by the relay lenses (1) and (2).

Then, the intermediate image formed again is reflected by the PBS 104, and formed on the SLM/CMOS 108 by the two relay lenses (A) and (B)

A portion of a photodetector element (CMOS sensor in this embodiment) of the SLM/CMOS 108 is placed only between pixels in a portion in which information light is irradiated.

Owing to the function of the mask element 104, unwanted reference light is not incident between pixels in a portion of the information light where photodetector elements are formed, whereby a reproducing signal with satisfactory S/N is obtained.

The light interference type SLM/CMOS 108 will be described with reference to FIGS. 5 to 7. FIG. 5 is a cross-sectional view (schematic view) of an element in which the light interference type spatial light modulator SLM and the photodetector element CMOS sensor used in the present invention are integrated vertically.

Reference numeral 31 denotes a Si substrate, 32 denotes a photodiode, 33 denotes a transfer transistor of a CMOS sensor, 34 denotes a CMOS sensor wiring, 35 denotes a SLM element wiring, 36 denotes a light-shielding film, 37 denotes a light interference mirror (A), 38 denotes a light interference mirror (B), 39 denotes a outermost surface protective film, 40 denotes an interlayer film, and 41 denotes a support. An interlayer insulator, other Tr wirings of a CMOS sensor, and Tr wirings for writing of the SLM are omitted.

In this drawing, an interference is caused between the light interference mirror (A) 37 and the light interference mirror (B) 38, and the space therebetween (e.g., air) is changed, whereby the reflectance and transmittance are changed.

The configuration in the drawing is of a vertically integrated type. According to this configuration, a transmission mode is also used for reading with a CMOS sensor, so both the mirrors need to be semi-transparent. However, in the case of a horizontal arrangement, a light interference portion is not required to be used for a transmission mode, so the light interference mirror (A) 37 does not need to be semi-transparent.

For example, Ti is used for a semi-transparent mirror. However, the present invention is not limited thereto. In the case where the mirror is not semi-transparent, a material with a high reflectance is preferable, and a metal film made of Al, AlSi, AlCu, Ti, Ta, W, Ag, Pt, Ru, Ni, Au, TiN, or the like, or a compound film made of any of the metals is used. However, the present invention is not particularly limited.

Reference numeral 41 denotes a support insulating film on a reflective electrode, which is, for example, a silicon nitride film. Reference numeral 39 denotes a protective film of a semi-transparent film, which is, for example, a silicon oxide film.

Insulating films 39, 40, and 41 may be made of different materials or the same material. As long as they are made of an insulating material, since there is no electrical problem, the present invention is not particularly limited.

The operation of the interference portion will be described. First, the light interference mirror (B) 38 of Ti is supplied with a ground potential of 0 V. The light interference mirror (A) 37 of Ti is supplied with a voltage by the above-mentioned active matrix operation, whereby the air gap is adjusted by the Coulomb force of the light interference mirrors (A) and (B).

FIG. 6 shows reflectances in a wide gap and a narrow gap with a layer configuration of an outermost surface protective film 39 (SiO_2: 10 nm), a light interference mirror (B) 38 (Ti: 5 nm/Si_3N_4: 20 nm/SiO_2: 10 nm/Si_3N_4: 20 nm), a gap 42 (170 nm in the case of a wide gap, and 10 nm in the case of a narrow gap), and a light interference mirror (A) 37 (Ti: 15 nm (SiO_2: 10 nm on the surface)).

For a light with a wavelength of 550 nm, the reflectances at air gaps of 170 nm and 10 nm are 52.5% and 1.2%, respectively.

It is understood that, when the air gap is changed from 10 nm to 170 nm by the voltage supplied to the light interference mirror (A) 37, the reflectance is changed largely accordingly.

The interference function can be designed depending upon the wavelength, semi-transparent film material, and air gap thickness, and it is important to design a required configuration considering the characteristics such as physical strength and a contrast ratio. Reference numerals 34, 35, and 36 denote underlying wiring layers, and 36 denotes a light-shielding layer, which prevents incident light from reaching a lower transistor region.

In the case of reading, regarding a pixel upon which at least information light becomes incident, it is necessary to keep a transmittance constant with the state of light interference being the same.

FIG. 7 shows a transmittance in the case where the air gap is set to be 10 nm. In this case, although the transmittance is relatively low (i.e., 23.0%), the absolute value of a transmittance is not so important because it is important that the transmittance is constant. Owing to the constant transmittance, the black and white intensities of the information light can be determined with the CMOS sensor.

Embodiment 2

FIGS. 8 and 9 each illustrate Embodiment 2 of a collinear holographic memory optical system of the present invention. The components having the same functions as those in Embodiment 1 are denoted with the same reference numerals as those therein. FIG. 8 is a detailed diagram of an optical arrangement of Embodiment 2. FIG. 9 is a cross-sectional view of a reflection type liquid crystal element used in the present invention.

As shown in FIG. 8, in the case of a reflection type liquid crystal (LCOS) element that changes a polarized state by 90° as the SLM (124), the quarter wavelength plate QWP 105 is not required. The detail of the remaining optical system is the same as that described in FIG. 4, so the description thereof will be omitted here.

Embodiment 2 will be described with reference to FIGS. 1 to 3.

Embodiment 2 is different from Embodiment 1 in the following point. A light beam passes through the relay lens (A) 106 and the relay lens (B) 107, and illuminates the SLM/ CMOS 108.

Light reflected by a pixel representing information "1 (white)" on the SLM is converted into S-polarized light, and light reflected by a pixel representing information "0 (black)" holds a state of P-polarized light.

In the same way as in the conventional example, provided on the collinear SLM are a portion for modulating the information light **110** and a portion for modulating the reference light **109** surrounding the information light **110** in an annular shape.

In FIG. **2**, among the light beams reflected by the SLM/CMOS **108**, the S-polarized light is reflected by the PBS **104** to be outputted to the hologram disk **118**, and the P-polarized light is transmitted through the PBS **104** and does not travel to the hologram disk **118**. The subsequent optical system is the same as that in Embodiment 1, so the description thereof will be omitted here.

FIG. **9** is a cross-sectional view (schematic view) of an element according to the present invention in which a reflection type liquid crystal (LCOS) spatial light modulator SLM and a photodetector element CMOS sensor are placed vertically.

Reference numeral **78** denotes a pixel electrode, **79** denotes an alignment film, **80** denotes a liquid crystals, **81** denotes an ITO, and **82** denotes a glass.

For example, assuming that the alignment film is a diagonally deposited SiO_2 film, the liquid crystal is a vertical liquid crystal, the pixel electrode is a semi-transparent film (e.g., with a reflectance of 50%), and **81** denotes a common electrode, in the "1" display, the pixel electrode is supplied with a voltage, and the liquid crystal is supplied with an electric field, whereby the liquid crystal molecules tilt.

In the "0" display, the liquid crystal is not supplied with an electric field, so the liquid crystal molecules rise substantially vertically. When light is transmitted through the polarizing beam splitter PBS as P-polarized light before being incident, and becomes incident as linear polarized light, in the "0" display the linear polarized light is reflected at an intensity of 50% by the pixel electrode without changing the polarized direction. The light becomes incident upon the PBS again. However, the polarization thereof is not changed, and the light is transmitted through again and does not reach the hologram.

On the other hand, at a time of the "1" display, the reflectance at the pixel electrode is 50%. However, light becomes linear polarized light rotated by 90°, so the light is reflected by the PBS as S-polarized light and written in the hologram. At this time, the thickness of the liquid crystal is designed so that a phase of $\lambda/2$ is generated by going forward and backward in the liquid crystal.

Even in the case of the "1" display, the intensity of light becomes 50%, which is a sufficient intensity for discriminating "1" from "0".

In the case of reading, the polarized state is not related, so the liquid crystal may be in any state.

Embodiment 3

FIG. **10** is a block diagram showing Embodiment 3 of a collinear holographic memory optical system of the present invention. The components having the same functions as those in Embodiment 1 are denoted with the same reference numerals as those therein.

In FIG. **10**, the optical path from the above-mentioned green laser **101** to the SLM/CMOS **108** is represented by a dot and dash line.

The relay lens system of this embodiment is composed of only two relay lenses. The relay lenses (A) **106** and (B) **107** are placed at a distance of 2f from the green laser **101** with f being a focal length.

The mask element **103** is placed at a distance f from the LD and between the green laser **101** and the relay lens (A) **106**.

The distance between the relay lenses (A) and (B) is 3f, and a light source image of the LD is formed at the same magnification by the relay lens (A), collimated by the relay lens (B), passes through the PBS **104** and the quarter wavelength plate QWP **105** successively, and becomes incident upon the SLM/CMOS **108** in the same way as in Embodiment 1.

In this embodiment, the PBS has angle dependency with respect to incident light. Therefore, this configuration enhances the extinction ratio, and is preferable for obtaining a satisfactory S/N.

Further, it is desirable that a light beam incident upon the SLM/CMOS **108** is collimated for the purpose of enhancing optical efficiency.

On the other hand, an optical path from the mask element **103** to the SLM/CMOS **108** is represented by a dotted line.

A mask image of the mask element **103** placed between the green laser **101** and the relay lens (A) **106** needs to be formed on the SLM/CMOS **108** to shield a required portion exactly.

Since the mask element **103** is provided at a distance f from the relay lens (A) **106**, the mask image is formed on the SLM/CMOS **108** by the relay lens (B) **107**.

FIG. **10** similarly shows a front view of the SLM/CMOS **108**.

On the SLM/CMOS **108**, a pattern **21** for reference light and a pattern **22** for object light are placed coaxially.

The mask image **23** shields the pattern for object light during reproduction of information.

As described above, the collinear holographic memory optical system of the present invention collimates a light beam transmitted through and reflected by the PBS and the modulating/photodetector element, and forms a mask element image on the modulating/photodetector element.

Embodiment 4

FIGS. **11** to **13** are diagrams illustrating optical systems of a collinear holographic memory of Embodiment 4 according to the present invention. FIG. **11** shows an optical system from a light source to a spatial light modulator during recording, and FIG. **12** similarly shows an optical system from the spatial light modulator to a hologram disk during recording. FIG. **13** shows an optical system during reproduction.

First, the case of recording information on a hologram disk **118** that is a recording medium will be described with reference to FIGS. **11** and **12**. In FIG. **11**, a light source outputted from a green laser **101** of a light source is collimated by a collimator **102**, and becomes incident upon a mask element **103**. The mask element **103** has a function of masking a portion corresponding to the information light in a center portion of a light beam.

In this embodiment, although a liquid crystal element is used as the mask element **103**, a mask shielding the center portion may be put in an optical path. During recording, the mask element **103** does not function, and transmits all the light beams.

In this embodiment, a liquid crystal element is used as the mask element **103**, for example, and a driving voltage from a drive circuit (not shown) to the liquid crystal element is switched on/off between recording and reproduction based on the control of a controller **152**. Accordingly, all the light beams are transmitted during recording, and a portion corresponding to the information light in a center portion of a light beam is masked during reproduction.

A light beam transmitted through a polarizing beam splitter PBS **104** as P-polarized light is transmitted through a quarter wavelength plate QWP **105** provided if required, and is transmitted through a relay lens (A) **106** and a relay lens (B) **107**.

Further, the light beam passes through a parallel plate **125** disposed so as to be tiltable with respect to the light beam, and illuminates an SLM/CMOS **108** with a spatial light modulator SLM and a CMOS sensor mounted on one chip.

The parallel plate **125** is configured so as to be tiltable with respect to an optical axis by the driving of a drive mechanism **150**. However, detailed description thereof will be made later. During recording, as shown in FIG. **11**, the parallel plate **125** is vertical to the optical axis without tilting. On the other hand, during reproduction, as described later, the parallel plate **125** is tilted with respect to the light beam by the control of the controller **152**.

As the drive mechanism **150** of the parallel plate **125**, for example, a drive mechanism with a plunger is used so as to switch the parallel plate **125** between a vertical state and a tilted state with respect to the optical axis. Then, the drive circuit **151** is controlled by the controller **152**, and the driving voltage from the drive circuit **151** to the drive mechanism **150** is switched on/off between recording and reproduction. Accordingly, the parallel plate **125** is made vertical to the light beam during recording, and tilted with respect to the light beam during reproduction.

Further, a stepping motor may be used for driving the parallel plate **125**. In this case, the parallel plate **125** is configured so as to be rotatable by the rotation of the stepping motor around the center thereof as shown in FIG. **13**, whereby the parallel plate **125** is switched between the vertical state and the tilted state with respect to the optical axis. Then, by switching on/off of a driving voltage from the drive circuit **151** to the stepping motor between recording and reproduction by the control of the controller **152**, the parallel plate **125** is made vertical to the light beam during recording, and is tilted with respect to the light beam during reproduction.

Herein, in the case of a light interference modulating element with a configuration of not changing a polarized state as an SLM, the quarter wavelength plate QWP **105** may be provided previously. Further, in the case of a reflection type liquid crystal (LCOS) element with a configuration of changing a linear polarized state by 90° as an SLM, the quarter wavelength plate QWP **105** is unnecessary.

In the case where the SLM/CMOS **108** is a light interference modulating element/CMOS element, a light beam transmitted through the quarter wavelength plate QWP **105** is converted into circular polarized light (e.g., clockwise circular polarized light), and passes through the relay lens (A) **106** and the relay lens (B) **107** to illuminate the SLM/CMOS **108**.

In FIG. **12**, the light beam reflected by the SLM/CMOS **108** becomes reverse circular polarized light (e.g., counterclockwise circular polarized light). Further, the light beam having passed through the parallel plate **125** and the relay lens (B) **107** and the relay lens (A) **106** is transmitted through the quarter wavelength plate QWP **105** to be converted into S-polarized light, and is reflected by the PBS **104** to be directed to the hologram disk **118**.

Further, in the case where the SLM/CMOS **108** is an LCOS element/CMOS element, the light beam passes through the relay lens (A) **106** and the relay lens (B) **107**, and illuminates the SLM/CMOS **108**. The light reflected by a pixel representing information "1 (white)" on the SLM is converted into S-polarized light, and light reflected by a pixel representing information "0 (black)" holds the state of P-polarized light. In the same way as in conventional examples, provided on the collinear SLM are a portion for modulating information light **110** and a portion for modulating reference light **109** surrounding the information light **110** in an annular shape.

In FIG. **12**, among the light beams reflected by the SLM/CMOS **108**, the S-polarized light is reflected by the PBS **104** to be directed to the hologram disk **118**, and P-polarized light is transmitted through the PBS **104** without being directed to the hologram disk **118**.

In any case, the reference light **109** and the information light **110** reflected by the pixel representing information "1 (white)" by the SLM of the SLM/CMOS **108** are reflected by the polarizing beam splitter PBS **104**. Further, the reference light **109** and the information light **110** pass through a relay lens (1) **111**, a mirror **112**, a relay lens (2) **113**, and a dichroic BS **114** to be directed to the hologram disk **118**, and are reflected by the mirror **115** to be incident upon an objective lens **116** at a focal distance f.

The hologram disk **118** is held so as to be rotatable on a spindle motor **117**. The reference light **109** and the information light **110** are condensed onto the hologram disk **118** by the objective lens **116**, and interfere with each other to form an interference fringe. On a polymer material in the hologram disk **118**, an interference fringe pattern during recording is recorded as a refractive index distribution, and a digital volume hologram is formed. Further, in the hologram disk **118**, a reflective film is provided.

In the same way as in Embodiment 1, in this embodiment, a red laser **119** having no photosensitivity with respect to the hologram disk **118** is provided in addition to the green laser **101** for recording and reproducing a hologram. Consequently, even when axial deflection and radial runout occur in the hologram disk **118**, a recording spot can be allowed to follow the recording medium surface dynamically, using an optical servo technique, and an interference fringe pattern can be recorded with high precision.

Next, the case of reproducing recorded information from the hologram disk **118** that is a recording medium will be described using FIG. **13**. A light beam outputted from the green laser **101** of a light source illuminates the SLM of the SLM/CMOS **108** in the same way as that of recording. During reproduction, as described above, the mask element **103** has a function of masking a portion corresponding to information light in a center portion of the light beam.

In this embodiment, a liquid crystal element is used to rotate the polarization direction only of the center portion of the light beam by 90° to form S-polarized light, and the S-polarized light is reflected by the subsequent PBS **104**, whereby the S-polarized light is prevented from reaching the SLM of the SLM/CMOS **108**. Alternatively, a mask shielding the center portion may also be inserted in an optical path.

Each of two relay lens (A) **106** and relay lens (B) **107** also has the function of forming an image of the mask element **103** on the SLM of the SLM/CMOS **108**. Only the portion of the element corresponding to the reference light is illuminated, and that corresponding to the information light is exactly shielded by the image (not shown) of the mask element **103**.

Only a portion for modulating the reference light **109** on the SLM/CMOS **108** displays information "1 (white)", and a portion for modulating the information light **110** displays information "0 (black)". Thus, only the light reflected by the pixel of the portion of the reference light is reflected to the hologram disk **118**. The light beam reflected by the pixel of the portion of the information light is not only reflected to the hologram disk **118** but also is not illuminated. Therefore, information light can be reproduced with better S/N compared with conventional examples.

During reproduction, the parallel plate **125** is tilted by θ with respect to the light beam by the driving of the drive mechanism **150** based on the control of the controller **152**. Thus, the light beam outputted from the green laser **101** and having passed through the relay lens (A) **106** and the relay lens (B) **107** is shifted only by s with respect to the light beam

during recording, and illuminates the SLM of the SLM/CMOS **108**. The light reflected by the pixel in the portion of the reference light passes through the parallel plate **125** again, and travels to the relay lens (B) **107** on the same optical axis as that of the forwarding path.

FIG. **14** is a detailed diagram of the parallel plate **125**. Assuming that the shift amount is s, the plate thickness of the parallel plate is t, and the tilt (tilt angle) is θ, a relationship between s and θ is as shown in FIG. **15**. In this case, the refractive index of the parallel plate **125** is 1.51, and t is 1 mm and 2 mm. In order to obtain a desired shift amount s described later, t and θ can be set arbitrarily.

In the same way as that of recording, the reference light **109** is reflected by the PBS **104** and condensed by the hologram disk **118**, and the information light is reproduced from a recorded interference fringe. The information light reflected by the reflective film in the hologram disk **118** becomes incident upon the objective lens **116** again to be collimated, and reflected by the mirror **115**. At this time, an intermediate image of a display pattern of the SLM reproduced at the distance f from the objective lens **116** is formed.

The light beam transmitted through the dichroic BS **114** passes through the relay lens (2) **113**, the mirror **112**, and the relay lens (1) **111**, and is directed to the polarizing beam splitter PBS **104**. Then, the light beam forms an intermediate image (not shown) of a display pattern of the SLM again at a position conjugate to the relay lens (2) **113**, the relay lens (1) **111**, and the mask element **103**. Then, the intermediate image formed again is reflected by the PBS **104**, passes through the two relay lens (A) **106** and the relay lens (B) **107**, and is further shifted by s by the parallel plate **125** to be formed on the SLM/CMOS **108**.

A photodetector element (CMOS sensor in this embodiment) portion of the SLM/CMOS **108** is placed only between pixels in a portion to be illuminated with the information light. Owing to the function of the mask element **103**, the unwanted reference light is not incident between pixels in a portion of the information light where the photodetector element is formed, so a reproduced signal with a satisfactory S/N is obtained.

In this embodiment, since the spatial light modulator SLM and the photodetector element CMOS sensor are placed on the same chip, a complicated alignment mechanism therefor and an expensive relay lens system can be eliminated, whereby cost down and compacting of the optical system can be achieved.

FIG. **16** is a cross-sectional view (schematic view) of an element in the case where the light interference type spatial light modulator SLM (**64** denotes an SLM element region) and the photodetector element CMOS sensor (**65** denotes a CMOS sensor region) according to the present invention are placed laterally.

In FIG. **16**, reference numeral **51** denotes a Si substrate, **52** denotes a photodiode, **53** denotes a transfer transistor of a CMOS sensor, **54** denotes a CMOS sensor wiring, **55** denotes a SLM element wiring, **56** denotes a light-shielding film, **57** denotes a light interference mirror A, and **58** denotes a light interference mirror B. Further, reference numeral **59** denotes an outermost surface protective film, **60** denotes an interlayer film, **61** denotes a support, **62** denotes a gap, and **63** denotes a SLM data transmitting switch. An interlayer insulator, other Tr wirings of a CMOS sensor, and Tr wirings for writing of the SLM are omitted.

In FIG. **16**, an interference is caused between the light interference mirror A **57** and the light interference mirror B **58**, and the space therebetween (e.g., air) is changed, whereby the reflectance and transmittance are changed.

Reference numeral **61** denotes a support insulating film on a reflective electrode, which is made of, for example, a silicon nitride film. Reference numeral **59** denotes a protective film of a semi-transparent film, which is made of, for example, a silicon oxide film.

Next, the operation of the interference portion will be described. First, the light interference mirror B **58** of Ti is supplied with a ground potential of 0 V, for example. Due to the above-mentioned active matrix operation, the light interference mirror A **57** of Ti is supplied with a voltage, and the air gap is adjusted by the Coulomb force of the light interference mirrors A and B.

FIG. **17** shows characteristics of reflectance at a time of "1" and "0" of the SLM of the light interference type spatial light modulator during recording. FIG. **17** shows reflectances in a wide gap and a narrow gap with a layer configuration of an outermost surface protective film **59** (SiO_2: 10 nm), a light interference mirror B **58** (Ti: 5 nm/Si_3N_4: 20 nm/SiO_2: 10 nm/Si_3N_4: 20 nm), a gap **62** (180 nm in the case of a wide gap, and 10 nm in the case of a narrow gap), and a light interference mirror A **57** (AlSi: 100 nm (SiO_2: 10 nm on the surface)).

For a light with a wavelength of 550 nm, the reflectances at air gaps of 180 nm and 10 nm are 93.0% and 0.6% respectively. It is understood that, when the air gap is changed from 10 nm to 180 nm by the voltage supplied to the light interference mirror A **57**, the reflectance is changed largely accordingly. The interference function can be designed depending upon the wavelength, semi-transparent film material, and air gap thickness, and it is important to design a required configuration considering the characteristics such as physical strength and a contrast ratio.

FIG. **18** is a cross-sectional view (schematic view) of an element according to the present invention in which a reflection type liquid crystal (LCOS) spatial light modulator SLM and a photodetector element CMOS sensor are placed laterally.

In FIG. **18**, reference numeral **66** denotes a pixel electrode, **67** denotes an alignment film, **68** denotes a liquid crystals, **69** denotes an ITO, and **70** denotes a glass. For example, assuming that the alignment film is a diagonally deposited SiO_2 film, the liquid crystal is a reflection film, and a common electrode is used for the ITO **69**, in the "1" display the pixel electrode is supplied with a voltage, and the liquid crystal is supplied with an electric field, whereby the liquid crystal molecules tilt. In the "0" display the liquid crystal is not supplied with an electric field, so the liquid crystal molecules rise substantially vertically.

When light is transmitted through the polarizing beam splitter PBS as P-polarized light before being incident, and becomes incident as linear polarized light, in the "0" display the linear polarized light is reflected by the pixel electrode without changing the polarized direction. The light becomes incident upon the PBS again. However, because the polarization thereof is not changed, the light is transmitted through again and does not reach the hologram. On the other hand, at a time of the "1" display, light becomes linear polarized light rotated by 90° (the thickness of the liquid crystal is designed so that a phase of $\lambda/2$ is generated by going forward and backward in the liquid crystal), so the light is reflected by the PBS as S-polarized light and written in the hologram.

Herein, the light beam incident upon the hologram disk **118** is adjusted and controlled so as to be incident exactly perpendicularly to the disk. In this case, an information light pattern generated on the SLM of the SLM/CMOS **108** becomes incident upon the SLM/CMOS **108** via the same path that the reflected light from the hologram disk **118** becomes incident.

FIG. **19** shows an exemplary positional relationship between the spatial light modulator SLM and the CMOS sensor on the SLM/CMOS **108**. As shown in FIG. **19**, the SLM and the CMOS each having the same area and the same shape are filled. The SLM and the CMOS form rows of pixels with a pitch (p) in which the SLM and the CMOS are placed at an equal interval. The direction represented by an arrow A in FIG. **19** corresponds to the shift direction of a light beam. The rows of pixels extend in a direction orthogonal to the direction represented by the arrow A. The pitch (p) is set to be the same as the shift amount (s) of the light beam. Owing to this configuration, a pattern image generated on the SLM during recording becomes incident upon the CMOS sensor shifted only by the pitch (p) during reproduction. Thus, a signal with a satisfactory S/N can be reproduced.

In this embodiment, the shift amount s is set to be the same as the pitch p of the pixel row. However, the shift amount s may be odd-number times as long as the pitch (p), and needless to say, it can be set arbitrarily in accordance with a layout. Further, the parallel plate **125** in the light beam is tilted, however, the parallel plate originally tilted with respect to the light beam may be inserted/removed with respect to the light beam, or a method having a similar effect may also be used.

Embodiment 5

FIG. **20** shows Embodiment 5 of the present invention. In FIG. **20**, the same portions as those in FIGS. **11** to **13** are denoted with the same reference numerals as those therein, and the description thereof will be omitted here. In this embodiment, the parallel plate **125** is omitted from the optical system, and the SLM/CMOS **108** is moved in a direction represented by an arrow B by the drive of the piezoelectric element **126**, instead. A pattern image generated on the SLM during recording becomes incident upon the CMOS sensor shifted by a pitch p during reproduction in the same way as in Embodiment 4.

Next, the case where recorded information is reproduced from the hologram disk **118** that is a recording medium will be described. In the following description, parts which are the features of this embodiment will be described. The SLM/CMOS **108** is attached to the piezoelectric element **126**, and can move in the direction represented by the arrow B perpendicular to a light beam incident upon the SLM/CMOS **108**.

During reproduction, the piezoelectric element **126** is energized with a drive circuit **153** by the control of the controller **152**, whereby the SLM/CMOS **108** is moved by a width (p) of the pixel row of the SLM/CMOS **108** in the direction represented by the arrow B with respect to the state of recording (see FIG. **19**). Accordingly, a reproduction signal with a satisfactory S/N and a large contrast can be obtained in the same way as in Embodiment 4. During recording, the piezoelectric element **126** is not energized, whereby the SLM/CMOS **108** is not moved.

In this embodiment, the piezoelectric element **126** is used as driving means for the SLM/CMOS **108**. However, the present invention is not limited thereto, and the SLM/CMOS **108** can be driven by various other driving means.

As described above, in Embodiments 4 and 5, the drive mechanism, drive circuit, and controller for shifting an incident light beam relatively in parallel to the SLM/CMOS **108** were used.

Embodiment 6

FIGS. **21** and **22** are diagrams each showing an optical pickup of an optical information recording and reproducing

apparatus according to Embodiment 6. FIG. **21** is a developed diagram of an optical system for a recording operation, and FIG. **22** is a developed diagram of an optical system for a reproduction operation. Further, FIG. **23** is a perspective view in the case where the optical system for a reproduction operation in FIG. **22** is placed as an actual optical pickup apparatus. The basic configuration thereof is the same as that of a conventional optical system shown in FIG. **39**, so in FIGS. **21** to **23**, the same portions as those in FIG. **39** are denoted with the same reference numerals as those therein.

Further, in FIG. **23**, the hologram disk **216** that is a hologram medium and an optical component for performing an optical servo technique using a red laser in a conventional example are omitted. Further, since FIGS. **21** and **22** are developed diagrams schematically showing each optical element, in FIGS. **21**, **22**, and **23**, the phase of each optical element with respect to an optical axis is varied.

Further, in this embodiment, the circuits such as a reproduction circuit for recording information, a recording circuit for reproducing information, or a servo control circuit, a mechanism such as a controller for controlling the entire apparatus, and the like are omitted, because they are known conventionally.

FIG. **24** shows an SLM/CMOS **301** used in Embodiment 6. In the SLM/CMOS **301**, an SLM **305** that is a spatial light modulator and a CMOS **306** that is a photodetector element are placed integrally so as to be adjacent to each other on the same plane on the same substrate (semiconductor substrate). Further, a polarization hologram element **302** that is a polarization splitter is placed between the SLM/CMOS **301** and the relay lens (**1**) **208**.

Further, as shown in FIG. **23**, the SLM/CMOS **301** is placed in a plane orthogonal to a disk surface (not shown in FIG. **23**) of the hologram disk **216**. Further, the SLM **305** in which the spatial light modulator is placed and the CMOS **306** in which the photodetector element is placed are disposed in parallel (in a direction represented by an arrow A in FIG. **23**) to the hologram disk surface. Such the configuration enables the apparatus to be thinned.

Next, the light interference type SLM/CMOS **301** integrally configured will be described. FIG. **25** is a cross-sectional view of a device in which a light interference type spatial light modulator SLM and a photodetector element CMOS sensor are placed laterally. FIG. **25** shows a configuration of one pixel of the spatial light modulator SLM and the photodetector element CMOS sensor.

In FIG. **25**, reference numeral **51** denotes a Si substrate, **52** denotes a photodiode, **53** denotes a transfer transistor of a CMOS sensor, **54** denotes a CMOS sensor wiring, **55** denotes a SLM element wiring, **56** denotes a light-shielding film, **57** denotes a light interference mirror A, and **58** denotes a light interference mirror B. Further, reference numeral **59** denotes an outermost surface protective film, **60** denotes an interlayer film, **61** denotes a support, **62** denotes a gap, and **63** denotes a SLM data transmitting switch. An interlayer insulator, other Tr wirings of a CMOS sensor, and Tr wirings for writing of the SLM are omitted.

Further, reference numerals **54**, **55**, and **56** denote underlying wiring layers, and the underlying wiring layer (light-shielding film) **56** is used for preventing incident light from reaching a lower transistor region. Reference numeral **64** denotes a region of an SLM element that is a spatial light modulator, and **65** denotes a region of a CMOS sensor that is a photodetector element.

In this embodiment, it is necessary that a light interference mirror B **58** using a transmission mode is semi-transparent. However, since the light interference portion does not need to

use a transmission mode, it is not necessary that a light interference mirror A **57** is semi-transparent.

For example, Ti is used for a semi-transparent mirror; however, the present invention is not limited thereto. In the case where the mirror is not semi-transparent, a material with a high reflectance is preferable, and a metal film made of Al, AlSi, AlCu, Ti, Ta, W, Ag, Pt, Ru, Ni, Au, TiN, or the like, or a compound film made of any of these metals is used. However, the present invention is not particularly limited.

Further, reference numeral **61** denotes a support insulating film on a reflective electrode, which is made of, for example, a silicon nitride film. Reference numeral **59** denotes a protective film of a semi-transparent film, which is made of, for example, a silicon oxide film. Insulating films **59, 60**, and **61** may be made of different materials or made of the same material. As long as they are made of an insulating material, there is no electrical problem, so the present invention is not particularly limited.

Next, the operation of the interference portion will be described. First, the light interference mirror B **58** of Ti is supplied with a ground potential of 0 V. Then, the light interference mirror A **57** of Ti is supplied with a voltage, whereby the air gap is adjusted by the Coulomb force of the light interference mirrors A and B.

FIG. **26** illustrates an example of spectral reflectance characteristics of the spatial-light-modulating/photodetector element **301**. FIG. **26** shows reflectances in a wide gap and a narrow gap with a layer configuration of an outermost surface protective film **59** (SiO_2: 10 nm), a light interference mirror B **58** (Ti: 5 nm/Si_3N_4: 20 nm/SiO_2: 10 nm/Si_3N_4: 20 nm), a gap **62** (180 nm in the case of a wide gap, and 10 nm in the case of a narrow gap), and a light interference mirror A **57** (AlSi: 10 nm (SiO_2: 10 nm on the surface)).

For a light with a wavelength of 550 nm, the reflectances at air gaps of 180 nm and 10 nm are 93.0% and 0.6% respectively. It is understood that, when the air gap is changed from 10 nm to 180 nm by the voltage supplied to the light interference mirror A **57**, the reflectance is changed largely accordingly. The interference function can be designed depending upon the wavelength, semi-transparent film material, and air gap thickness, and it is important to design a required configuration considering the characteristics such as physical strength and contrast ratio.

Next, an operation in the case where recording is performed with respect to the hologram disk **216** will be described using FIG. **21**. A basic recording method is the same as that described above.

Reference light **205** and information light **206** reflected by a pixel representing information "1" by an SLM **305** of an SLM/CMOS **301** are transmitted through a polarization hologram element **302** as P-polarized light, and are directed to a hologram disk **216** via a relay lens (**1**) **208**, a mirror **209**, a relay lens (**2**) **210**, and a dichroic BS **211**. At this time, the reference light **205** and the information light **206** transmitted through a quarter wavelength plate QWP **212** and converted into circular polarized light (e.g., clockwise circular polarized light) are reflected by a mirror **213** to be incident upon an objective lens **214** at a focal length f.

A pattern displayed on the SLM **305** by the two relay lenses (**1**) **208** and (**2**) **210** forms an intermediate image at a distance f before the objective lens **214**. Consequently, a so-called 4f optical system in which a pattern image (not shown) on the SLM, the objective lens **214**, and the hologram disk **216** are placed with an interval f from each other is configured. The hologram disk **216** is held rotatably on the spindle motor **215**.

The reference light **205** and the information light **206** are condensed on the hologram disk **216** by the objective lens **214**, and interfere with each other to form an interference fringe. On a polymer material in the hologram disk **216**, an interference fringe pattern during recording is recorded as a refractive index distribution, and a digital volume hologram is formed. Further, a reflective film is provided in the hologram disk **216**. The description of the optical servo means for allowing an optical spot to follow the hologram disk **216** is omitted, since it is similar to that in the conventional example.

Next, an operation in the case where recorded information is reproduced from the hologram disk **216** will be described using FIG. **22**. A light beam outputted from the green laser **201** of a light source illuminates the SLM **305** of the SLM/CMOS **301**. During reproduction, only a portion for modulating the reference light **205** on the SLM **305** displays information "1", and a portion for modulating the information light **206** displays information "0". Thus, only the light reflected by the pixel in the portion of the reference light is reflected to the hologram disk **216**, and the information light is not reflected to the hologram disk **216**.

In the same way as that in recording, the reference light **205** becomes circular polarized light (e.g., clockwise circular polarized light) to be condensed onto the hologram disk **216**, and reproduces information light from the recorded interference fringe. Information light reflected by the reflective film in the hologram disk becomes reverse circular polarized light (e.g., counterclockwise circular polarized light) to be incident upon the objective lens **214** again and collimated.

Further, the light beam is reflected by the mirror **213** and transmitted through the quarter wavelength plate QWP **212**, and is converted into a linear polarized light beam (S-polarized light) perpendicular to the polarization direction of the forwarding path. At this time, an intermediate image of a display pattern of the SLM **305** reproduced at the distance f from the objective lens **214** is formed.

The light beam transmitted through the dichroic BS **211** passes through the relay lens (**2**) **210**, the mirror **209**, and the relay lens (**1**) **208** to be directed to the polarization hologram element **302** as S-polarized light. The light beam diffracted and deflected by the polarization hologram element **302** is guided to the CMOS **306** of the SLM/CMOS **301** shown in FIG. **24**, and reproduces recorded information.

With such a configuration, the illumination light **303** and the reproduced information light **206** can be separated from each other so as not to degrade the S/N, and a spatial light modulator and a photodetector element can be configured integrally. Consequently, an optical system can also be miniaturized.

Further, as shown in FIG. **27**, it is also possible that the CMOS **306** is placed only in a region that is irradiated with the information light **206**. Accordingly, during reproduction, the unwanted reference light reflected by the hologram disk **216** is not incident upon the CMOS **306**, whereby a reproduced signal with a better S/N can be obtained.

The polarization hologram element **302** is placed between the SLM/CMOS **301** and the relay lens (**1**) **208**. However, the present invention is not limited thereto.

Embodiment 7

FIGS. **28** to **31** are diagrams illustrating Embodiment 7 of a collinear holographic memory optical system according to the present invention. FIG. **28** is a developed diagram of an optical system of an optical pickup, and FIG. **29** shows an SLM region and a CMOS region of the SLM/CMOS **301**.

FIG. **30** is a cross-sectional view showing a state of reference light and information light of the SLM/CMOS **301** during a recording operation. FIG. **31** is a cross-sectional view

showing a state of reference light and information light of the SLM/CMOS **301** during a reproduction operation. The basic configuration and operation are the same as those of Embodiment 6, so the detailed description thereof will be omitted.

Further, even in this embodiment, the circuits such as a reproduction circuit and a recording circuit for recording or reproducing information, a servo control circuit, and a controller for controlling an entire apparatus, a mechanism, and the like are known, so an explanation thereof will be omitted.

In this embodiment, as shown in FIG. **29**, pixels constituting SLM regions **64** and CMOS regions **65** respectively on the same substrate are arranged alternately in a horizontal direction and a vertical direction, and pixels constituting the SLM regions **64** and the CMOS regions **65** are arranged in a checkered pattern.

Further, as shown in FIGS. **30** and **31**, in an SLM/CMOS **301**, a polarization hologram element **302** is integrally formed on the SLM regions **64** and the CMOS regions **65**. Further, on the CMOS regions **65**, polarizing filters **304** are provided.

The above-mentioned configuration will be described with reference to FIG. **31**. As shown in FIG. **31**, in the reproduction operation described later, it is assumed that an angle at which the information light **206** is diffracted by the polarization hologram element **302** and deflected is θ, and a distance between a light receiving plane of the CMOS region **65** and a plane on which the information light **206** is deflected by the polarization hologram element **302** is y. At this time, a displacement x between the optical axis before deflection in the direction orthogonal to y and the optical axis at a time when a light beam reaches the CMOS region **65** is represented by x=y·tan θ. Therefore, x corresponds to the pitch of the respective pixels of the SLM region **64** and the CMOS region **65**. Thus, in order to integrate the polarization hologram element **302** and the SLM/CMOS **301** in a small size (set y to be small), it is desirable that the respective pixels are arranged alternately in the horizontal direction and the vertical direction as shown in FIG. **29**. However, in a case where y and θ are sufficiently large, for example, the arrangement of the SLM **305** and the CMOS **306** as shown in FIG. **24** may be used.

In the SLM/CMOS **301** in which the polarization hologram element **302** is configured integrally, for example, by using a resin or a glass having polarization characteristics as a material for sealing a chip in which the SLM region **64** and the CMOS region **65** are formed, the above-mentioned arrangement can be realized easily.

Next, a recording operation will be described in detail with reference to FIGS. **28** and **30**. In the same way as in Embodiment 6, the illumination light **303** directed to the spatial light SLM/CMOS element **301** as P-polarized light is transmitted through the polarization hologram element **302** placed on the SLM/CMOS **301**, and illuminates the SLM region **64**.

At this time, in the same way as in Embodiment 6, the reference light **205** and the information light **206** reflected by a pixel representing the information "1" on the SLM region **64** are transmitted through the polarization hologram element **302** again as P-polarized light, and is guided to the relay lens (**1**) **208**. The optical system, servo system, and the like after the relay lens (**1**) **208** are the same as those of Embodiment 6, and the description of the subsequent recording operation will be omitted.

Next, a reproduction operation will be described in detail with reference to FIGS. **28** and **31**. In the same way as in Embodiment 6, the illumination light **303** directed to the SLM/CMOS **301** as P-polarized light is transmitted through the polarization hologram element **302** placed on the SLM/CMOS **301**, and illuminates the SLM region **64**. The refer-

ence light **205** reflected by the pixel representing the information "1" on the SLM region **64** is transmitted through the polarization hologram element **302** again as P-polarized light, and is guided to the hologram disk **216** in the same way as in Embodiment 1.

The information light **206** reproduced from the hologram disk **216** is transmitted through the dichroic BS **211** as S-polarized light, and is directed to the polarization hologram element **302** via the relay lens 2 (**210**), the mirror **209**, and the relay lens 1 (**208**).

At this time, the information light **206** incident upon the polarization hologram element **302** is diffracted and deflected by the polarization hologram element **302**, and is guided to the CMOS region **65** of the SLM/CMOS element **301**, as shown in FIG. **31**. Recorded information is reproduced from the output of the CMOS region **65**.

Herein, in the arrangement of the SLM region **64** and the CMOS region **65** shown in FIG. **29**, the respective pixels are adjacent to each other, so the CMOS region **65** receiving the information light **206** is also irradiated with the illumination light **303** for generating the reference light **205**. In this embodiment, as shown in FIGS. **30** and **31**, the polarizing filter **304** for transmitting only the S-polarized light is placed on the CMOS region **65**.

With the above-mentioned configuration, the influence by the illumination light **303** that is P-polarized light is removed, and the information light **206** diffracted and deflected as S-polarized light can be received in the CMOS region **65**. In the case where the illumination light is radiated as S-polarized light, the polarization direction in which the illumination light is diffracted by the polarization hologram element **302** is P-polarized light, so the same effect can be obtained by placing a polarizing filter for transmitting only P-polarized light.

In Embodiment 7, the polarization hologram element **302** and the SLM/CMOS **301** are integrally formed, so each positional precision can be obtained satisfactorily as compared with Embodiment 6. Further, it is also possible to reduce the number of parts, so the time for assembly can be reduced, and costs can be reduced.

Further, in the same way as in Embodiment 6, only the pixels in a region irradiated with the information light **206** can be set to be the CMOS **306**. For example, as shown in FIG. **29**, the SLM regions **64** and the CMOS regions **65** are placed alternately with respect to the A region in the vicinity of the center. In the remaining region, only the SLM regions **64** are placed. Accordingly, the unwanted reference light reflected by the hologram disk **216** is not incident, whereby a reproduced signal with a better S/N is obtained during reproduction.

The present invention is not limited to the above-mentioned embodiment. For example, not only a green laser but also a blue violet semiconductor laser that has been put into practical use recently may be used as a light source for holography. Further, not only a disk-shaped medium but also a card-shaped medium can also be used as the hologram medium. Further, as the spatial light modulator, a digital mirror device (DMD) can also be used.

Embodiment 8

FIGS. **32**A and **32**B are diagrams each showing an optical path of an optical information recording and reproducing apparatus for recording a hologram on a recording medium by allowing two light beams to interfere with each other according to Embodiment 8.

FIG. **32**A shows the operation at a time of recording, and FIG. **32**B shows that at a time of reproduction.

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First, the operation at a time of recording will be described.

Among the light beams from a laser light source **411**, a light beam transmitted through a PBS **417** becomes reference light, is reflected by a mirror **418**, a mirror **419**, and a galvanometer mirror **420**, and is guided to a scanning lens **421**. The scanning lens **421** irradiates a hologram recording medium **422** with the reference light.

Herein, an expander **412** aligns light beam diameters to a desired diameter. A pin-hole **413** is a spatial filter for adjusting wavefronts. A shutter **414** is prepared for controlling the exposure time during recording. An apodizer **415** is a filter for making the intensity distribution of light beams to be uniform in a plane. A half wavelength plate **416** is variable in rotation, and changes the polarization direction of a light beam incident upon the PBS **417** during reproduction described later so as to prevent light transmitted through the PBS **417** from being generated.

On the other hand, among the light beams from the laser light source **411**, a light beam reflected by the PBS **417** is reflected by a PBS **426**, and is incident upon an SLM/CMOS sensor integrated element **441** (hereinafter, referred to as "SLM/CMOS **441**"). The incident light beam is reflected by being subjected to two-dimensional modulation corresponding to predetermined information due to the spatial modulation function of the SLM/CMOS **441**, and has its polarization direction changed to become information light. The reflected light beam is transmitted through the PBS **426**, and the objective lens **431** irradiates the hologram recording medium **422** with the reference light.

Herein, the expander **423** has a function of adjusting the diameters of light beams to be the information light. A phase mask **424** is a filter for enhancing the uniformity of the intensity distribution of light in the hologram recording medium condensed by the objective lens. A relay lens **425** overlaps a two-dimensional pattern image of the phase mask **424** on the SLM/CMOS **441**. A relay lens **428** forms an image of a two-dimensional pattern by the spatial modulating function portion of the SLM/CMOS **441** on which the two-dimensional pattern image of the phase mask **424** is overlapped, on an incident side focal plane of the objective lens **431**. A quarter wavelength plate **442** changes the light incident upon the SLM/CMOS **441** to circular polarized light, and changes the light reflected by the SLM/CMOS **441** to linear polarized light transmitted through the PBS **426**. A polytopic filter **429** is an aperture for restricting the mixing of reproduced light from an outside of a desired hologram during hologram reproduction described later.

Next, the operation at a time of reproduction will be described.

During reproduction, the polarization direction of a light beam from the laser light source **411** is changed by the half wavelength plate **416**, whereby the light beam is prevented from being reflected by the PBS **417**. The light beam transmitted through the PBS **417** is reflected by the mirror **418**, the mirror **419**, and the galvanometer mirror **420**, and is guided to the scanning lens **421** to be irradiated to the hologram recording medium **422** by the scanning lens. At this time, although diffracted light due to a hologram recorded on the hologram recording medium **422** is generated, the diffracted light is not used as information reproducing light.

The light beam transmitted through the hologram recording medium **422** is reflected by the galvanometer mirror **432**, and becomes incident upon the hologram recording medium **422** as reference light. The incident angle of the reference light with respect to the hologram recording medium **422** is controlled by the galvanometer mirror **420** and the galvanometer mirror **432**.

The reference light irradiated to the hologram recording medium **422** generates diffracted light due to the hologram recorded on the hologram recording medium **422** to become information reproducing light. The information reproducing light is collected by the objective lens **431**, and the information reproducing light other than the information reproducing light corresponding to the reference light incident angle controlled by the galvanometer mirror **420** and the galvanometer mirror **432** is attenuated by the polytopic filter **429** to be incident upon the PBS **426**. The light beam incident upon the PBS **426** is transmitted through the PBS **426** to be incident upon the SLM/CMOS **441**.

Further, since the SLM portion and the CMOS sensor portion are integrated, the half wavelength plate **430** for polarization separation is not required in the PBS **426** during recording and reproduction.

Thus, the light beam incident upon the SLM/CMOS **441** is converted into an electric signal by the image receiving function portion of the SLM/CMOS **441**, and two-dimensional pattern information corresponding to a desired hologram recorded on the hologram recording medium **422** is reproduced.

Herein, the SLM/CMOS **441** of this embodiment will be described.

FIG. **33** is a cross-sectional view (schematic diagram) of one pixel of the SLM/CMOS **441** according to this embodiment.

This embodiment is characterized in that the SLM portion and the CMOS sensor portion are integrated three-dimensionally along an optical axis.

Reference numeral **451** denotes an Si substrate; **452**, a photodiode; **453**, a transfer transistor of a CMOS sensor; **454**, a CMOS sensor wiring; **455**, a SLM element wiring; **456**, a light-shielding film; **457**, a light interference mirror A; **458**, a light interference mirror B; **459**, an outermost protective film; **460**, an interlayer film; and **461**, a support. An interlayer insulator, the remaining transistor wiring of the CMOS sensor, and transistor wiring for writing of an SLM are omitted.

In this embodiment, interference is caused between the light interference mirror A **457** and the light interference mirror B **458** to change the space therebetween, whereby the reflectance and the transmittance are changed.

More specifically, a case where the mirrors are set to have a wide gap is used as a high reflectance mode. A case where the mirrors are set to have a narrow gap is used as a high transmittance mode. That is, during recording, the reflected light is subjected to spatial modulation based on recording information of two values, that is, high reflectance in the wide gap and low reflectance in the narrow gap. During reproduction, light is guided to the CMOS sensor portion by setting the SLM portion in a high transmittance mode in a narrow gap, and the information reproducing light is converted into an electric signal in the CMOS sensor portion.

Herein, the SLM/CMOS sensor integrated element **441** is produced in the same semiconductor process by successively forming a CMOS sensor and a transistor on a Si substrate, and thereafter, forming an interlayer film and each wiring.

Thus, the spatial light modulating portion and the image light receiving portion are formed on the same substrate in the same semiconductor process, so high-precision alignment between the spatial light modulator and the image receiving element as in the conventional example is not required. Further, by integrating the spatial light modulating portion with the image light receiving portion, space can be saved as compared with the conventional example in which the spatial light modulator and the image receiving element are provided separately.

Embodiment 9

Next, Embodiment 9 will be described.

The optical path of the optical information recording and reproducing apparatus is the same as that of Embodiment 8. Further, the spatial light modulating portion and the image light receiving portion are formed on the same substrate in the same semiconductor process in the same way as in Embodiment 8.

The difference from Embodiment 8 will be described below.

In this embodiment, the SLM/CMOS sensor integrated element **441** is a planarly integrated element, in which the SLM portion **464** including the light interference mirror A **457** and the light interference mirror B **458**, and the CMOS sensor portion **465** including the photodiode **452** are adjacent to each other along a plane vertical to the optical axis, as shown in FIG. **34**.

FIGS. **35**A to **35**C each show an arrangement example of the spatial light modulating portions and the image light receiving portions. The black portions represent image light receiving portions. FIG. **35**A shows an example in which the spatial light modulating portions and the image light receiving portions are arranged with the same shape in the same area. FIGS. **35**B and **35**C show examples in which the image light receiving portions are enlarged to enhance the sensitivity of light reception.

Thus, in the same way as in Embodiment 8, the high-precision alignment of the spatial light modulator and the image photodetector element as in the conventional example is not required. Further, by integrating the spatial light modulating portion with the image light receiving portion, space can be saved as compared with the conventional example in which the spatial light modulator and the image photodetector element are provided separately.

In this embodiment, the transmission mode as in Embodiment 8 is not required as spatial light modulating portion performance. Therefore, it is possible to increase the reflectance of the spatial light modulating portion, which can increase the use ratio of light during recording of information.

Embodiment 10

Embodiment 10 will be described.

FIGS. **36**A and **36**B are diagrams each showing an optical path of this embodiment. The difference from Embodiment 8 lies in that the quarter wavelength plate **442** shown in FIGS. **32**A and **32**B is eliminated by the use of the SLM/CMOS sensor integrated element **443** of a reflection liquid crystal type.

In the same way as in FIGS. **32**A and **32**B, FIG. **36**A show an operation at a time of recording, and FIG. **36**B shows that at a time of reproduction.

FIG. **37** is a cross-sectional view (schematic view) of the SLM/CMOS sensor integrated element **443** of a reflection liquid crystal type, in which the spatial light modulating portion and the image light receiving portion are arranged three-dimensionally along an optical axis.

Reference numeral **466** denotes a pixel electrode; **467**, an alignment film; **468**, a liquid crystal; **469**, an ITO; and **470**, a glass. The alignment film **467** is a diagonally deposited SiO_2 film, the liquid crystal **468** is a vertical liquid crystal, and the pixel electrode **466** is a semi-transparent film having a reflectance of about 50%.

During recording, in a case where the liquid crystal **468** is not supplied with an electric field, light incident upon the liquid crystal **468** is reflected at an intensity of 50% by a pixel

electrode without changing the polarization direction. The light beam enters the PBS **426** again, is reflected by the PBS **426** because the polarization is not changed, and does not reach the hologram recording medium **422**. In a case where the liquid crystal **468** is supplied with an electric field, the liquid crystal molecules tilt. Since the thickness of the liquid crystal **468** is set so that a phase shift of $\lambda/2$ is caused by going forward and backward in the liquid crystal **468**. Therefore, the reflected light by the SLM portion becomes linear polarized light rotated by 90°, and is transmitted through the PBS **426** to reach the hologram recording medium **422**.

Thus, the light is subjected to two-dimensional modulation corresponding to predetermined information, and contributes to the recording of information.

On the other hand, in the case of reproduction, the polarized state is not related, so the liquid crystal may have any state.

In the case of this embodiment, the quarter wavelength plate **442** can be eliminated, so an optical system can be simplified as compared with Embodiment 8.

Embodiment 11

Next, Embodiment 11 will be described.

The optical path of the optical information recording and reproducing apparatus is the same as that of Embodiment 10.

The difference from Embodiment 10 will be described below.

In this embodiment, the SLM/CMOS sensor integrated element **443** is a planarly integrated element, in which the SLM portion **464** including the pixel electrode **466**, and the CMOS sensor portion **465** including the photodiode **452** are adjacent to each other along a plane vertical to the optical axis, as shown in FIG. **38**.

The arrangement of the spatial light modulating portions and the image light receiving portions is the same as that illustrated in FIGS. **35**A to **35**C.

In this embodiment, as spatial light modulating portion performance, the pixel electrode **466** does not need to be a semi-transparent film unlike Embodiment 10, and the reflectance of the spatial light modulating portion can be enhanced. Further, the transmission loss during reproduction is eliminated, and hence, the use efficiency of light can be enhanced.

As describe above, according to the present invention, a spatial light modulator SLM and a photodetector element CMOS sensor are arranged on the same chip. Therefore, the complicated alignment mechanism thereof and the expensive relay lens system are omitted, whereby cost down and compacting of the optical system can be achieved.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application Nos. 2005-343882, filed Nov. 29, 2005, 2005-343884, filed Nov. 29, 2005, 2006-131450, filed May 10, 2006, and 2006-307896, filed Nov. 14, 2006, which are hereby incorporated by reference herein in their entirety.

What is claimed is:

1. An optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light, comprising:

a light source;

a spatial light modulator for generating at least an information light with respect to a light beam from the light source;

an objective lens for irradiating a recording medium with the light beam from the spatial light modulator; and

a photodetector element for receiving a reproduction light from the recording medium,

wherein the spatial light modulator and the photodetector element are formed on a same semiconductor substrate,

wherein the light beam from the light source is generated into the information light and the reference light having the same optical axis, based on the spatial light modulator, and

wherein a pixel constituting the spatial light modulator and a pixel constituting the photodetector element are arranged alternately in a horizontal direction and a vertical direction on the semiconductor substrate.

2. An optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light, comprising:

a light source;

a spatial light modulator for generating at least an information light with respect to a light beam from the light source;

an objective lens for irradiating a recording medium with the light beam from the spatial light modulator;

a photodetector element for receiving a reproduction light from the recording medium,

wherein the spatial light modulator and the photodetector element are formed on a same semiconductor substrate, and are arranged coaxially in a light incident direction,

wherein the light beam from the light source is generated into the information light and the reference light having the same optical axis, based on the spatial light modulator; and

further comprising a mask element provided between the semiconductor substrate and the light source,

wherein the mask element transmits the light beam from the light source during recording of information, and blocks a light beam in a portion corresponding to the information light and transmits a light beam in a portion corresponding to the reference light during reproduction of information.

3. An optical information recording and reproducing apparatus according to claim 1, further comprising a mask element provided between the semiconductor substrate and the light source,

wherein the mask element transmits the light beam from the light source during recording of information, and blocks a light beam in a portion corresponding to the information light and transmits a light beam in a portion corresponding to the reference light during reproduction of information.

4. An optical information recording and reproducing apparatus according to claim 1, further comprising a drive mechanism for shifting an incident light beam relatively in parallel with respect to the spatial light modulator and the photodetector element between recording and reproduction.

5. An optical information recording and reproducing apparatus according to claim 4, wherein the drive mechanism is placed in a light beam between the light source and the semiconductor substrate, and has a parallel plate for shifting the light beam,

wherein the parallel plate is driven so as to be perpendicular or tilted with respect to the light beam.

6. An optical information recording and reproducing apparatus according to claim 4, wherein the drive mechanism drives the semiconductor substrate in a direction perpendicular to the light beam.

7. An optical information recording and reproducing apparatus according to claim 1, further comprising a polarization beam splitter element for guiding the reproduction light to the photodetector element between the semiconductor substrate and the objective lens.

8. An optical information recording and reproducing apparatus according to claim 7, wherein the polarization beam splitter element is configured so as to be integrated with the semiconductor substrate.

9. An optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light, comprising:

a light source:

a spatial light modulator for generating at least an information light with respect to a light beam from the light source;

an objective lens for irradiating a recording medium with the light beam from the spatial light modulator;

a photodetector element for receiving a reproduction light from the recording medium,

wherein the spatial light modulator and the photodetector element are formed on a same semiconductor substrate; and

further comprising a beam splitter element for splitting a light beam from the light source,

wherein the information light is generated from one of the split light beams based on the spatial light modulator, and the other of the split light beams is radiated to the recording medium as the reference light in an optical axis different from that of the information light, and

wherein a pixel constituting the spatial light modulator and a pixel constituting the photodetector element are arranged alternately in a horizontal direction and a vertical direction on the semiconductor substrate.

10. An optical information recording and reproducing apparatus for recording information by allowing information light and reference light to interfere with each other and reproducing the information using the reference light, comprising:

a light source;

a spatial light modulator for generating at least an information light with respect to a light beam from the light source;

an objective lens for irradiating a recording medium with the light beam from the spatial light modulator;

a photodetector element for receiving a reproduction light from the recording medium,

wherein the spatial light modulator and the photodetector element are formed on a same semiconductor substrate; and

further comprising a polarization beam splitter element for guiding the reproduction light to the photodetector element between the semiconductor substrate and the objective lens.

11. An optical information recording and reproducing apparatus according to claim 10, wherein the polarization beam splitter element is configured so as to be integrated with the semiconductor substrate.

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